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Practical Ability

BY
VEDA PRAKASHA

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ABBREVIATIONS

B. J. E. P.	The British Journal of Educational Psychology.
B. J. P.	The British Journal of Psychology.
J. App. P.	The Journal of Applied Psychology.
J. Ed. P.	The Journal of Educational Psychology.
J. Ex. P.	Journal of Experimental Psychology.
Occup. P.	Occupational Psychology.

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The views expressed in this monograph are those of the writer only.

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FOREWORD

PRACTICAL ability is an important mental function. After intelligence, it is one of the more significant components of human personality to be taken into account in educational and vocational guidance. One of the popular classifications of human beings into 'theoretical' and 'practical' types derives from the lack or possession of this ability. And yet the term 'Practical ability' is very vague ! Different research workers have employed different kinds of tests to determine the nature of the function. At least four different kinds of tests have been used to study its composition, namely, performance tests of intelligence, tests of mechanical aptitude, tests of motor and manual abilities and tests of space perception. Should the ability sampled by these different kinds of tests be the same, the factorial examination of their structure must produce evidence to that effect, otherwise the practice of using different kinds of tests for studying the same function will only add to the confusion. The only proper method to attack the problem would be to make a factorial study using a large number of tests of each type and see whether the analysis shows any similarity of factorial structure as between different types of tests. But before this is done, it would be worthwhile to examine whether the researches carried out by different workers so far do or do not throw any light on the similarity or otherwise of the functions involved.

The present study by Shri Veda Prakasha is an attempt in this direction. It gives a detailed account of important researches bearing on the nature of practical ability and shows that as far as present evidence can be relied upon, practical "ability as measured by performance tests or tests of mechanical ability or tests of space perception seems to consist of two identifiable factors, namely, general intelligence and the ability to appreciate space relations. This does not mean that the score of a given child on a certain test of practical ability will be entirely dependant upon the two factors, *g* and *k*; it is certain that in any particular test performance, specific factors will also come into the picture. All that is meant is that the two factors that appear to be more constantly present than others in tests of practical ability are *g* and *k*".

I have no doubt that this critical review of researches on practical ability would be found useful by those who are interested in the study of this function.

Central Institute of Education,
January, 1956.

A. N. Basu
Principal

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CHAPTER I

Introduction

DIFFERENT research workers have given different definitions of practical ability. Stenquist, one of the earliest investigators in the field, for instance, identified practical ability with mechanical ability and defined the latter as "general aptitude in the management and manipulation of things mechanical",[1] the term mechanical being interpreted not in the narrow sense of having to do with machines but more widely in the sense of concerned with or involving material or concrete objects. McFarlane gave a similar definition and wrote "The present writer would reserve the term 'practical ability' for the subject's *total response* to a problem of a certain kind, viz. one which demands for its solution changing some portion of the physical world. Such usage is in accord with every day custom. Practical ability includes therefore :

(a) Grasp of the problem.

(b) Ability to plan the series of movements necessary to bring about the change.

(c) Ability to execute the movements successfully".[2]

Alexander, on the other hand, attempted a more precise definition by regarding practical ability "...as that ability or combination of abilities which can be measured by performance tests of intelligence"[3]; and concerning the essential nature of performance tests of intelligence, he wrote : "Performance tests are measures of intelligence in which there is a practical task to be done which involves and stresses thinking rather than mere manual dexterity...As far as possible such tests should be measuring the same type of thinking that is measured in verbal tests, as for expample eduction of relations, eduction of correlates, ...Our purpose is to use a practical medium rather than a verbal medium as a means of measurement of intelligence".[4]

There are several other definitions of practical ability available, but these are also of an *a priori* character. As the present study deals primarily with *experimental* data bearing on the nature of this function, it is not proposed to go into the examination of these definitions.

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[1] Stenquist, J. L. *Measurements of Mechanical Ability*, Teachers College, Columbia University, New York, 1923, p. 3.

[2] McFarlane, M. "A Study of Practical Ability", B.J.P., Mon. Supp. 8, 1925, p. 16.

[3] Alexander, W.P. "Intelligence, Concrete and Abstract". B.J.P., Mon. Supp. 19, 1935, p. 20.

[4] Ibid., p. 20.

Apart from theoretical discussions on the nature of practical ability, there have been in the main two rather different kinds of approaches adopted by research workers in their investigations of the precise nature of practical ability. The earlier of these approaches has consisted mainly in making an introspective analysis of the abilities required in the carrying out of a given type of practical job, such as the job of a mechanical engineer, usually after closely watching the worker on his job for some time. This introspective type of approach is exemplified in the study of "The make-up of the engineering worker"[1] made by Max Tagg. As a result of watching the successful performance of the various operations pertinent to their jobs by different kinds of engineering workers and later by making an introspective analysis of the data so obtained, Max Tagg arrived at the conclusion that some of the more important abilities required by an engineering worker in the execution of his job were these :

(a) *Perception of Space and Form.* "...Quite apart from the *technique* and conventions of the drawing, this ability of 'seeing into the solid' is essential for this type of worker..."[2]

(b) *Memory of form, size, etc.* "...However efficient a worker may be, if he cannot pick out the 16-23 tool he requires without looking at the mark, much time will be wasted..." [3]

(c) *Motor Ability.* "Motor ability is an essential in the make-up of all engineering workers, from the skilled draughtsman to the unskilled, automatic-machine hand ...it is highly complex and is as little dependent on the suppleness of individual muscles as the efficiency of a steam engine is on the lubrication of its moving parts. It involves imagery—probably kinaesthetic as well as visual..." [4]

Intropective studies of Max Tagg's kind may often contain valuable suggestions for further research, but their findings are likely to be vitiated to an unknown extent by the personal equation of the observer. Present day investigators show a general distrust of the introspective approach and employ it only when the more objective techniques are inapplicable or when in the interpretation of results obtained by other methods the use of introspective analysis promises information otherwise unobtainable.

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[1] Tagg, M. "The make-up of the engineering worker", Journal of the National Institute of Industrial Psychology, Vol. I, 1923, pp, 313-324.

[2] Ibid., p. 318.

[3] Ibid., p. 319.

[4] Ibid.,

The other kind of approach—with which this study is principally concerned—consists mainly in studying the nature of practical ability by examining statistically the results obtained by giving various kinds of tests supposed to measure practical ability to representative samples of subjects. This approach has the advantage of being more objective than the earlier approach and is consequently the one most frequently employed by the present day investigators. Since, however, most of such objective studies make use of factor-analysis, a certain amount of introspection is indispensable in these also, being necessary to the interpretation of the factors obtained.

But perhaps the greatest snag about this approach is that different investigators have employed different kinds of tests—supposed to sample the same practical function—in their researches. While considering these investigations, it is important to remember that the results obtained by a particular investigator have been determined among other things by the kind of tests employed by him. In the circumstances the only sound plan to follow in reviewing the important investigations on practical ability would be to examine them in the context of the types of measures employed.

In the main research workers have employed four different kinds of tests of practical ability, namely, (a) Performance tests of intelligence ; (b) Tests of mechanical ability or mechanical aptitude ; (c) Tests of motor and manual abilities ; and (d) Group tests of space-perception. It is now proposed to give a brief description of the chief characteristics of each type.

Performance Tests of Intelligence

"Performance tests in general are practical problems which require for their solution the manipulation of some concrete material or the performance of some specific act."[1]

They are called performance tests because they call mainly for action rather than for mere thought, although successful action requires effective thinking. These tests were originally devised as tests of general intelligence especially for deaf subjects and others who suffered from language handicaps of various kinds. Use of the correlational techniques during the last three decades or so, however, revealed a tendency among some of the performance tests to correlate more highly with one another than with general intelligence as measured by the Binet and other verbal scales of intelligence. This led to the suggestion that over and above general intelligence, (some of the) performance tests also called for another ability which has sometimes been interpreted as the ability to appreciate space relations. A relatively recent and perhaps the most well-known research on performance tests is that of Alexander who in a factorial study of the three performance tests constituting his scale of practical ability and certain verbal measures of intelligence isolated a general factor and two group factors, one common to the performance tests and the other to the verbal tests. Alexander called the former "F" but gave no interpretation of it beyond recording the fact that F was peculiar to the performance tests and certain other practical school subjects, and that F seemed to constitute the differentiating mark of practical ability in the same sense in which the verbal factor constituted the distinguishing feature of verbal ability. Thus while practical and verbal abilities were similar in that both called for general intelligence they differed in that while the additional factor involved in the former was practical, it was verbal in the latter.

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[1] Industrial Fatigue Research Board, Report 53, 1929, p. 2,

Tests of Mechanical Ability or Mechanical Aptitude

Tests constructed to measure mechanical ability or aptitude are of many kinds, a rather well known variety being Stenquist's "Assembly Tests" in which the subject is required to put together the parts of simple mechanisms encountered in everyday life, such as a lock or a bicycle bell. Perhaps the most important research on such tests is that by Cox, who employed his own tests of mechanical aptitude requiring the subjects to solve problems related to diagrams or models made of pulleys, wheels, levers, slots, springs, cog-wheels, etc.along with certain verbal tests of general intelligence treated as reference values. Analysing the resulting correlation coefficients by the tetrad-analysis criterion, Cox found evidence for a single factor, besides the general factor common to all the tests used, running through all the various types of his mechanical tests. He labelled this factor '*m*' and followed Spearman in the latter's enunciation of his three fundamental laws of cognition, in giving it a spatial interpretation.

Tests of Motor and Manual Abilities

Tests of motor and manual abilities in the past have often been interpreted, especially by some of the earliest investigators, such as Muscio[1], Ballard and others, as tests of practical ability partly because the more highly developed practical tests were not then available, but mainly because motor and manual abilities seem to form an essential component of mechanical ability as required in executing a large number of mechanical jobs. A mechanic, for example, requires not only the understanding of the complex inter-relationships of the parts of a given machine, but also the manipulation of tools and other mechanical objects of varying degree of complexity and the performance with their aid of complex manual and bodily movements. There is a strong contemporary tendency, more prevalent it seems in the United Kingdom than in America, to ignore as far as possible a consideration of the motor and manual abilities in discussions on the nature of practical ability, probably because motor and manual performance seems to depend more on the physiological efficiency of the organism than on any cognitive determinants of behaviour. The intercorrelation between various measures of manual abilities are as a rule of a very low order, indicating that the factors involved are highly specific; sometimes, however, indications of group factors of restricted range have also been reported, notably by Cox and Farmer.

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[1] Muscio, B. "Motor capacity with special reference to vocational guidance", B.J.P., Vol. 13, 1922, p. 184.

Group Tests of Space-Perception

These are perhaps the most important kind of non-verbal mental group tests and were first constructed in America during the war of 1914-18 when the question arose of measuring the intelligence of illiterate and semi-literate recruits in the American army. At present there is quite a wide choice of them available, for example, Form Relations Group Test (National Institute of Industrial Psychology), Group Test 80 (N.I.I.P.), The Minnesota Spatial Relations Test, etc. The material employed in these tests is not concrete but consists of 'shapes' or drawings, which share with concrete objects their two-dimensional and sometimes three-dimensional spatiality. The fact that these tests have often yielded higher correlations with one another and with certain performance tests of the formboard and cube construction type, and that they have also yielded significant correlations with some of the practical occupations calling *inter alia* for the ability to appreciate space relations, has been commonly interpreted as evidence that over and above the general factor which such tests are known to measure quite effectively, there is also an additional factor of space perception running through them. One of the more well-known researches on tests of space-perception is that of Koussy who isolated a '*k*' factor in some of his spatial tests which he interpreted as the ability—"to obtain, manipulate and utilise *visual spatial imagery*."[1]

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[1] Koussy, A.A.H.El, "An Investigation Into the Factors in Tests Involving the Visual Perception of Space." B.J.P. Mon. Supp. 20, 1935, p, 86.

With these introductory observations we may pass on to the next chapter which addresses itself to a detailed description of the important tests of practical ability of each type and a critical review of researches bearing on the psychological nature of this function.

CHAPTER II

A critical review of researches on Practical Ability

IT was stated earlier that the term 'tests of practical ability' lacks in precision, and has been used variously to refer to any of the following four types of tests : (a) performance tests, (b) tests of mechanical ability, (c) tests of motor and manual abilities. and (d) group tests of space-perception. The reasons for regarding these apparently different kinds of tests as measures of the same practical function were only touched upon there. In explicit terms the following considerations may be stated. In performance tests the practicality of the ability involved is determined by the mental as well as physical manipulation necessary to deal with test-materials of a concrete nature. In tests of mechanical ability whether manipulative such as the Stenquist assembly tests or non-manipulative such as Cox's tests of mechanical aptitude, the ability called for is considered practical since it concerns the understanding of the relationships obtaining between the different parts of a concrete mechanism either presented actually or represented diagrammatically. The reason for considering motor and manual tests as tests of practical ability lies in the fact that the abilities sampled by them appear to be necessary to the execution of many mechanical jobs. There are numerous examples of factorial studies on mechanical ability, particularly in American literature to which reference will be made later, in which tests of motor and manual functions have been thrown together with other tests of mechanical ability in the same test-batteries. Lastly, group tests of space-perception are regarded as particularly valid tests of practical ability partly because many of these tests were originally devised as group tests of the individual form-board type calling for the appreciation of space relations and partly because there is considerable evidence that the nature of the practical factor as isolated in numerous experinental investigations on practical ability is visuo-spatial.

The above four-fold classification of tests of practical ability into (a) performance tests, (b) tests of mechanical ability, (c) tests of motor and manual abilities, and (d) group tests of space-perception, it should be remembered, is employed merely for descriptive convenience; it is quite likely that considering its chief characteristic, as far as those can be judged from the nature of the material employed and the purpose it is supposed to serve, a given test may simultaneouly belong under more than one of the above four heads. The Cube Construction Test[1] for example, is normally treated as a performance test; since, however, it also involves a certain amount of manual skill in handling wooden blocks, especially in the case of younger children, it can on that account also be regarded as a test of manual dexterity.[1] Again Earle and Macrae[2] have employed this test as a measure of mechanical ability in one of their investigations on that function. In another experiment, Earle and Milner[3] classify the test under a group of tests whose most important feature is suggested as the necessity for apprehending spatial relations. Indeed, unless such plural classification were possible in the case of many tests usually treated as tests of practical ability, it would be seriously open to question at the very outset whether the different kinds of tests grouped together as measures of practical ability were really measuring the same psychological function at all.

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[1] See *Industrial Fatigue Research Board, Report 31*, 1925, p. 22.

It is now proposed, retaining the above four-fold classification, to describe briefly the origin and development of different kinds of tests of practical ability and the important researches carried out on them. Investigations by Alexander, Cox and Koussy to which only passing reference was made in the foregoing chapter have also been included for fuller treatment.

Performance Tests of Intelligence

The first performance test was in the form of a formboard and was used early in the nineteenth century by Itard, a French physician in educating an idiot boy known as the "Wild Boy of Aveyron" and later with infant idiots. Seguin also working in France with mental defectives in the later half of the nineteenth century constructed a series of similar tests of the formboard type and used them with mental defectives; his formboards were later standardized by Goddard as measures of intelligence. The first application of formboards as a measure of individual differences was made by Norsworthy in 1908. Formboards have also been found useful by Montessori and other educationists in the training of normal children.

This early work with formboards was mainly independent of the development of intelligence testing, which originated in the well-known work of Binet in Paris. Various translations and revisions of the Binet tests appeared in different countries soon after their construction in 1908.[4] There were, however, some serious limitations to their general application. To mention just a few of these, the tests were unsuitable for use with subjects, speaking languages in which satisfactory translations of the tests were not available, with subjects who suffered from some language handicap and especially with subjects who were deaf. There was yet another objection to the use of these tests with normal children; the predominantly verbal character of the scale gave an undue advantage to subjects with facility in verbal expression. Binet himself was aware of this last defect and tried to rectify it by including a number of non-verbal tests, such as the picture interpretation and paper cutting tests. Even so, his scale remained largely verbal, particularly at the higher age levels. Burt has since statistically shown that over one-half of the gross score obtained in the Binet tests is attributable to school attainment and that "Linguistic ability and linguistic attainments exert upon the Binet-Simon tests a special and positive influence of their own."[1] These and other limitations of the Binet scale urged upon those interested in psychological measurement the need for new tests which should aim at eliminating, as far as possible, the verbal element from the test situation. The available formboard tests met this requirement admirably and were readily adopted for use as the first performance tests of intelligence. In such tests the complexity is introduced into the tests either by making the forms similar so that fine discrimination is required, or by dividing the blocks to be inserted so that two or more pieces are required to fill a single hole.

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[1] As however the amount of manipulation required is not very great, it is not customary to treat the test as a measure of manual skill.

[2] See *The National Institute of Industrial Psychology, Report 3*, p. 26.

[3] See *Industrial Fatigue Research Board, Report 53*, p. 39. 1929

[4] See *Mental Tests* by F. N Freeman, Houghton Mifflin Company, Boston, 1939 Ed., p. 90.

"Among the next performance tests to be used were those of a 'picture completion' type, in which a dissected picture is to be fitted together again to make an intact whole—a simplified form of which later became popular as jig-saw puzzle."[2] One well-known series of such completion tests was that devised by Healy.

In 1913 Porteus devised a series of tests known as the Porteus Maze tests. In these mazes which are graded progressively in difficulty and which cover an age range from 3 to 14 inclusive, the subject is required to find his way out by tracing through straight line mazes printed on separate sheets of paper. Porteus mazes have been widely used throughout the world in many anthropological investigations as well as in the measurement of intelligence of normal and abnormal subjects. A brief summary of all the important investigations carried out on these tests is given in *The Psychology of a Primitive People* by Porteus, (pp. 357-359).

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1. Burt, C. *Mental and Scholastic Tests*, Staples Press Limited, London, 1947 Ed., p. 196.
2. *Industrial Fatigue Research Board, Report 31*, 1925, p. 7.

The famous Kohs' Block Design Test was first devised by Kohs in 1919 and has since undergone several standardizations.

Correlations of individual performance tests with verbal intelligence tests were frequently reported to be very low. When, however, batteries of performance tests were used, and the results pooled, the correlations increased significantly. A number of such performance scales were consequently standardized, the more well-known of which are chosen for description below.

1. *The Healy and Fernald Scale.*

The earliest non-verbal scale was that devised by Healy and Fernald. The scale consisted of 22 miscellaneous tests of which the more important performance tests were these : Introductory Picture Form Board, Construction Puzzle (A), Construction Puzzle (B), Puzzle Box. The scale also included the well-known 'Aussage' Test intended to measure the individual's ability 'to give accurate testimony.' In their monograph which appeared in 1911, the authors suggested some of the limitations of the Binet scale in these words: 'It helps very little where the language factor is a barrier, either on account of foreign parentage or insufficient schooling, and with uneducated, deaf and dumb children"[1] and went on to recommend the use of their own scale in situations where the Binet scale was inapplicable particularly in the case of testing the intelligence of young offenders.

2. *The Knox Scale*[2].

Knox devised a series of performance tests for use with non-English speaking immigrants at Ellis Island. All his tests were not equally good however, and the better ones were included by several investigators in their own performance scales standardized later.

3. *The Pintner-Paterson Scale.*

This is a very well-known scale of performance tests and has been widely used in America. It includes these 15 tests, the Mare and Foal Picture Board, the Seguin Form Board, the Five Figure Board, the Two Figure Board, the Casuist Form Board, the Triangle Test, the Diagonal Test, the Healy Puzzle "A", the Manikin Test, the Feature Profile Test, the Ship Test, the Picture Completion Test, the Substitution Test, the Adaptation Board and the Cube Test. In their work called "Performance Tests"? which first appeared in 1917, the authors gave a detailed description of the standardization data for each test separately. The scale was designed primarily for use with deaf children and was also recommended for use in situations where the Binet scale was inappropriate. As it stands, however, the scale has a very definite disadvantage of requiring a long time to administer.

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[1] Healy, W. and Fernald, G. M. "Tests for practical mental classification," Psychol. Mon. 54, 1911, p. 5.

[2] Knox, H. A. "A scale for estimating mental defect," Journal of the American Medical Association, 1914, pp. 741-747; mentioned by Koussy in his work referred to on page 5.

4. *Grace Arthur's Point Performance Scale.*

The scale was first published for use in 1925[1] and included these tests, Knox Cube, Seguin Form Board, Two Figure Form Board, Casuist Form Board, Manikin and Feature Profile, Mare and Foal, Healy Picture Completion and Kohs' Block Design. The author adopted the point method of scoring because this is more useful relatively than the median mental age and the Binet year methods of scoring. In a restandardization of the scale in 1928[2] on approximately 1100 public school children, the Porteus mazes were also included in the scale.

5. *The Dearborn, Shaw, Lincoln Scale.*

This scale consisted of the following 10 performance tests; Color-Form Test, Form Board IA, Form Board IC, Form Board 2 Reconstruction Puzzle, Form Board 3, Form Board 4, Triangle Performance Test, Lincoln Hollow Square, Shaw Picture Puzzles and Furniture Test. In the last test the parts of a small rocking chair were presented to the subject with instructions to make the necessary piece of furniture by using all the pieces. The test was very similar to Kelley's test of constructive ability, a description of which first appeared in 1916 in the Journal of Educational Psychology. A full description of the scale appeared in a Harvard Monograph in Education entitled "A Series of Form Board and Performance Tests of Intelligence" published in 1923. The point about which the authors felt most convinced was the usefulness of the form board tests as part of the clinical examination. To the question: What did their performance tests measure? they proposed the following answer: "It seems altogether possible that the various types of performance tests differ somewhat as to the traits which they measure. Form Boards like No. 3 perhaps measure rather specifically the conception of form and manipulative skill, while those like the Picture Completion and Furniture tests are more general in their nature and require abstract thinking in some degree for their successful completion. It is possible that we shall discover that performance tests of general intelligence must be of this latter type".[3]

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[1] Arthur, G. "A new point performance scale," J. App. P., Vol. 9, 1925, pp. 390-416.

[2] Arthur, G. "The restandardisation of a point performance scale," J. App. P., Vol. 12, 1928, pp. 278-303.

[3] Dearborn, W.F., Shaw, E.A., and Lincoln, F.A. "A series of form board and performance tests of intelligence," Harvard Monographs in Education, 4, 1923, p. 64.

6. *Drever and Collins Scale.*

The scale includes these 8 tests : Block Design Test, Knox Cube Test, Domino Test, Size and Weight Test, Manikin and Profile Test, Form Boards Test, Cube Construction and Picture Completion Tests. *Performance Tests of Intelligence* by the authors (Drever and Collins) was first published in 1928 and gave adequate directions for giving and scoring the tests. In two subsequent editions of this book the authors made several important alterations regarding the instructions and norms of the various tests. The authors supported the Thorndikian theory of three types of intelligence and believed that while verbal scales tested merely the abstract type of intelligence, performance tests measured a type which was more practical and "...which plays an important part in the practical work of the world".[1]

7. *The Alexander Performance Scale.*

This performance scale comprises three tests : The Passalong, Kohs' Block Design and the Cube Construction. A full description of the scale first appeared in 1946,[2] although all the three tests included in the scale had been used by the same author (Alexander) in an earlier enquiry concerning the nature of abstract and practical abilities.

On the Nature of Abilities Measured by Performance Tests

Although, as has already been stated, the performance tests were originally developed as instruments for the measurement of general intelligence in non-verbal material, there has been lack of agreement among the workers regarding the nature of ability sampled by these tests. In general, two kinds of answers have been provided to the question : What do performance tests meausure ? one based on opinion and common sense and the other on experimental investigation. The answers given by the earliest investigators are of the first type. A few representative opinions of this kind may be stated first before passing to the experimental evidence.

Healy and others considered that, in a scale of performance tests, the individual tests measured different abilities or traits, but the whole scale formed a good measure of intelligence.

To the viewpoint of Dearborn, Shaw and Lincoln reference was made on page 11.

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[1] Drever, J., Collins, M. *Performance Tests of Intelligence*, Oliver and Boyd, Edinburgh, 1944 Ed., p. 16.

[2] Alexander, W. P. *Instruction Book, A Performance Scale for the Measurement of Practical Ability*. Thomas Nelson and Sons, Ltd., Edinburgh, 1946.

Wallin suggested that performance tests measured a special ability which he called the "form sense" and which he interpreted as the ability to discriminate between, or recognise different forms, shapes or spatial relations, "to analyse objective situations and to manipulate concrete material and creative and reproductive constructiveness".[1]

Among the experimental investigations on this subject, the earliest study is that reported by Gaw in 1925.[2] She gave 14 performance tests, comprising several tests from the Pintner and Paterson scale, several tests from the U.S. Army Performance scale and Porteus mazes to 100 L.C.C. elementary school pupils (52 boys and 48 girls of mean age 13.5). She found that the degree to which the performance tests correlated one with another was almost exactly the degree to which they correlated with the Binet I. Q. She interpreted this as evidence that the central factor measured by performance tests was largely general intelligence. She also reported some sex differences in favour of the boys.

In an investigation designed primarily for the determination of the existence and nature of practical ability, McFarlane[3] gave certain garment and wood construction tests of her own design along with certain other standard performance tests to 405 children (boys and girls) divided into 12 small homogeneous groups to control the effect of age, training, sex, and selection on test performance. She found that for the boys, the intercorrelations of the performance tests among themselves were markedly higher than their correlations with the verbal tests; for the girls the order of magnitude was approximately the same throughout. From this she concluded that there was a special ability consisting of a simple general factor or of a complex of many factors positively correlated with one another, common to the practical tests in the case of boys as distinguished from girls. Since, however, she did not apply any tetrad analysis criterion to her data, it is difficult to determine whether higher intercorrelations in the case of boys were due to a factor common to all her tests, or whether they were due to a number of factors in which there was some overlapping. McFarlane also reported that while the girls made a higher score in the particular test (garment construction) known to have a special interest for them, in all the others, both those intrinsically interesting to boys, and those which had no special attraction for either sex, they made a much poorer score than the boys. From this and certain other data she further concluded that practical ability was not so important a factor in determining the performance of girls as it was in that of boys. Again, however, in addition to assuming the existence of practical ability, she also failed to apply any tests of significance to her data concerning sex differences. Even granting that the sex differences reported by her were significant, it is highly probable that they were due more to the differential effect of past experience of the two sexes than to the supposed fact that boys possessed the ability in question in a higher degree than girls.

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[1] Wallin, W. *Abnormal and Clinical Psychology*, George G. Harrap and Company Ltd., London, 1927, pp. 213-and 247.

[2] Gaw, F. "A study of performance tests," B. J. P., Vol. 15, 1925, pp. 374-392.

[3] McFarlane, M. op. cit.

Spearman[1] critically examined the results of an experiment carried out by McCrae in which the latter employed seven performance tests designed as spatial tests and three reference non-spatial tests. The spatial tests were Porteus Maze, Cube Construction, Goddard Formboard, Dearborn Formboard, Triangle Test, the Diagonal Test, Healy Construction Test A; the non-spatial tests being: Picture Completion, Cube Imitation and Substitution. Spearman subjected the experimental data to tetrad analysis. Besides the general factor common to all the tests, there was no evidence of a spatial factor peculiar to the spatial tests.

In a later enquiry Earle and Milner published the results of an extensive investigation in which about 600 children of about 14 years of age were given a group test of verbal type and 9 performance tests, namely, Mazes (Porteus), Cube Imitation (or Knox Cube Test), Substitution (Woodworth and Wells), Picture Completion II (Healy), Formboard (Dearborn), Cube Construction, Picture Completion I (Healy), Formboard (Goddard) and Profile Test. Several other tests of immediate visual memory, spatial perception and mechanical ability were also given to some of the subjects for comparative purposes. One of the relevant conclusions arrived at by the investigators was as follows. "As to the existence of 'group' factors over a wider range—such as the so-called 'non-verbal' or 'practical' ability—there is, however, no conclusive evidence. That there is a factor common to all the performance tests is certain; but whether it consists only of the 'general factor' common to all mental tests or of this factor in combination with some group factor cannot be decided on the evidence of these results."[2]

A detailed factorial study of his performance scale was made by Alexander[3] in 1935. His work was particularly designed to prove or disprove the hypothesis that there is a special factor over and above *g* common to performance tests of intelligence. Four groups of subjects were tested. With the first group (100 pupils from a Scottish elementary school, 52 boys and 48 girls, mean age 142.4 months), the Passalong, Kohs' Block Design, Cube Construction, three of Cox's tests and three measures of intelligence were used. Three common factors were isolated, the results revealing a "functional clustering" of the three performance tests on the one hand and three verbal intelligence tests on the other. For the second group (71 boys from two academic high schools in New York, mean age 15 years, 11 months), the intelligence measures were divided into four purely verbal measures and two number-verbal. Cox's tests were also included. A factor-analysis of the results again revealed three factors—a *g* factor common to all the tests, a *v* factor common to the verbal tests and F factor common to the performance tests. Three of Spearman's *g* tests were used additionally with each of the remaining two groups. The third group (103 boys from a technical high school in Chicago, mean age 16 years, 11 months) had also scores in school achievement in shopwork, mechanical drawing, mathematics, science and English and group 4 (100 delinquent women all above 16 years of age) some other performance tests, namely, five Formboard tests, Picture Completion Test and Porteus Maze Test. A factor-analysis of the resulting data in the two groups again revealed *g* common to all the tests, *v* common to the verbal tests and F common to the performance tests. The analysis of the third group also showed two additional factors, 'X' and 'Z' common to achievement in various school subjects. Tentative identification was given to X as 'Persistence' but nothing determinate was said regarding Z beyond suggesting that it seemed to be a factor of some importance in school achievement.

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[1] Spearman, C. *The Abilitities of Man,* MacMillan & Co., Limited, London, 1927, p. 228.

[2] *Industrial Fatigue Research Board, Report 53,* 1929, p. 67.

[3] Alexander, W.P. op. cit.

In general the findings of Alexander's investigation are fairly impressive and seem to have established that over and above general intelligence there is a factor F running through all the performance tests. But what is the psychological nature of F? What mental function can be common between such dissimilar tests as the Healy Picture Completion Tests and the formboard tests? Is the function involved mainly perceptual concerned with distinguishing between objects of different shapes and sizes, or is it mainly manipulative, concerned with the handling and controlling of concrete test materials? Alexander gave no answer to this question. His designation of F as the practical factor does not seem to help very much in interpreting the true psychological nature of the factor.

MacMeeken[1] surveyed the verbal and non-verbal abilities of representative Scottish children (443 boys and 430 girls, age ranging from 8:11 to 11:9 in the extreme cases). The tests included the 1916 Stanford-Binet, Seguin Formboard, Manikin, Stutsman Picture, Red Ridinghood Picture, Healy Picture Completion II, Knox Cube Imitation, Cube Construction and Kohs' Block Designs. The resulting correlations were subjected by Thomson to Thurstone's centroid analysis. Analysis was done for the data from each sex separately and four factors were isolated in each case. Thomson concluded: "But it seems also pretty clear that the only two factors which are at all certain are the general factor—possibly but not necessarily to be identified with *g*—and the rhythm or speed factor linking tests 1, 2 and 3.[1] (These were the Seguin Board, Manikin and Stutsman Picture). There was no evidence for a verbal factor entering into the Binet tests but as Burt points out "...the choice of tests was hardly suited to demonstrate conclusively the existence or the influence of such a factor."[2] There was some evidence for a space factor (common to Knox Cube Imitation, Kohs' Block Designs and Cube Construction) but it was not at all conclusive.

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[1] MacMeeken, A. M. *The Intelligence of a Representative Group of Scottish Children*, University of London Press, Ltd., London, 1939.

Heston[3] reported an American investigation by Morris in which several tests were given to 56 boys of about 9½ years of age. The tests included were, the whole Pintner-Paterson scale, several formboards, the Block Designs, the Porteus Maze and several others. An analysis of the resulting correlations revealed three factors which were identified as: Visualising, Perceptual Speed and Induction. In his own factorial study of some clinical performance tests Heston applied 18 test variables to a homogeneous group of 113 men. The more well-known of his tests were, Healy Picture Completion II, Knox Cubes. Ferguson Formboards, Kohs' Block Designs and Minnesota Spatial Relations (Boards A and B). A centroid analysis of the data revealed three significant factors, two of which were identified as (a) a spatial factor—"the ability to visualise spatial shapes and relationships"—and (b) a speed factor—"the ability for rapid movement and dexterity of manipulation." The third factor was rather ambiguous, a possible interpretation suggested by Heston being in terms of the "ability to readily grasp non-spatial Gestalt relationships."[4]

To summarise the experimental studies on performance tests: in the earlier investigations studied mainly by the correlational and Spearman's tetrad-analysis methods the weight of evidence is against the hypothesis of the existence of a common factor, over and above general intelligence; the more recent evidence, however, studied by the more advanced factorial techniques favours the view that there is such a factor and that probably it is spatial in nature.

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[1] Thomson, G. H. *An Analysis of Performance Test Scores of a Representative Group of Scottish Children*, University of London Press, Ltd., London, 1940.

[2] Burt, C. (A review of) *An Analysis of Performance Test Scores of a Representative Group of Scottish Children* by G.H. Thomson, B.J.E P., Vol. 10, 1940, p. 243.

[3] Heston, J.C., "A factor-analysis of some clinical performance tests," J.App.P., Vol. 27, 1943, p. 135.

[4] Ibid., p. 147.

Tests of Mechanical Ability

Apart from performance tests which have been used not infrequently as tests of mechanical ability, the earliest tests which were specifically designed to measure mechanical ability seem to be the assembly tests of Stenquist and later the ingenious mechanical comprehension tests designed by Cox to which reference was made in the foregoing chapter. Another relatively new type of mechanical ability tests which are coming into common use in the present day investigations in the field of vocational guidance and vocational selection consists of the paper-and-pencil type information tests, the chief assumption underlying their construction being "...that the individual who is mechanically-minded will have, in the course of his development, acquired more information about tools and mechanical processes than another individual not so inclined."[1]

The earliest experimental investigation on tests of mechanical ability was carried out by Stenquist[2] who, after standardising three series of his assembly tests which have been widely used in the same or modified form in many subsequent researches, compared the scores of various groups of subjects made on his own tests with the results obtained by the same subjects in verbal intelligence tests and also with the ranks of manual instructors. The correlations with intelligence were generally low, rarely exceeding 0.4. The correlations with shop instructors' ranks, on the other hand, were high, sometimes as high as 0.9. As a result of his studies, Stenquist was so much impressed with the effect of supplementing the usual verbal general intelligence tests with tests of mechanical ability that he questioned the legitimacy of calling any test which neglected the mechanical aspect of mental ability, a test of general intelligence. The statistical treatment of his data was, however, of a very indadequate nature and hence it is not necessary to examine his conclusions further.

In an investigation carried out by Earle and Macrae[3] to determine the nature of mechanical ability two groups of subjects-one of 125 Elementary school boys and another of 100 Secondary school boys were studied on these tests—Mechanical Ability Test (Assembly type), Cube Construction Test, Formboard Test, Picture Completion Test, Cube Imitation Test, Form Relations Test and a verbal group test of intelligence. For some of the subjects certain manual dexterity and speed of movement tests were also included. An analysis of the correlational data revealed that success in the Mechanical Assembly Test depended on the following three factors :

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[1] Bennett, G. K., and Cruikshank, R. M., *A Summary of Manual and Mechanical Ability Tests,* The Psychological Corporation, New York, 1942, pp. 2-3.

[2] Stenquist, J. L. op. cit.

[3] *The National institute of Industrial Psychology, Report 3, 1929.*

(a) A general factor common to all the tests used.

(b) A factor of space-perception common to the Assembly Test, Form-Relations, Cube Construction and the Dearborn Formboard.

(c) A factor of manual dexterity common to the Assembly Test and the manual dexterity test.

The importance of this research lies mainly in producing evidence that success in the Assembly Test required, in addition to general intelligence, the use of a factor of space perception also running through some of the performance tests and the Form Relations Test used in the study.

The models used by Cox were so constructed as to eliminate completely the influence of manual dexterity. He gave these and certain other tests of mechanical ability to three groups, a group of untrained commerce subjects varying from 14 years to adult age (the group was further divided for the study of sex-differences into two sub-groups, group A consisting of boys and group B of girls), a group of 114 elementary school boys whose age ranged from 10 years to 14 years 3 months and a group of 228 students taking the Passing Out Examination of a large R.A.F. Technical School, all above 18 years of age. Analysing the correlational data by the tetrad analysis technique he found evidence in his mechanical tests for a group factor, in addition to the general factor common to all the measures employed. He labelled the group factor '*m*' and interpreted it in spatial terms after Spearman's definition of his three Noegenetic principles. The following quotation gives Cox's interpretation of *m*.

"The outstanding feature in which the *m* tests differ from the customary 'intelligence' tests,...is the spacial character of the material employed, together with that particular kind of thinking about this material...Such thinking involves not merely the apprehending of certain spacially arranged items, as in design, nor solely in the eduction of their space-relations...superimposed on this definite arrangement of parts is movement..."[1]

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[1] Cox, J. W. *Mechanical Aptitude*, Methuen & Co., Ltd., London, 1928, p. 160-161.

Cox believed that mechanical aptitude as measured by his tests was inborn and not dependent on training and past experience.

Sometimes the criticism has been made that since *m* was isolated in relation to verbal tests of intelligence and since such tests usually have a verbal factor over and above the general factor, it is quite possible that the factor isolated by Cox resided with the verbal and not with the mechanical tests. Rao's[1] research in which he employed reference values of a perceptual nature, some spatial, together with the *m* tests furnishes an answer to this question. He found evidence for *m* factor in the mechanical tests but there was no evidence for a group factor in the spatial tests. Rao's interpretation regarding the genetic nature of *m* was, however, opposed to that of Cox. He suggested that *m* may be due to 'special knowledge and interest in mechanical objects,' a spatial interpretation being rendered impossible since there was no evidence for a spatial factor. Rao's viewpoint appears to be more plausible than Cox's since not only did some of the latter's tests require verbal ability to a considerable extent, but they also assumed the subject's equal acquaintance with mechanical objects such as levers, wheels, cogs etc.—an assumption for which Cox gave no justification whatever. These facts coupled with the further fact that Cox failed to find *m* in the case of his girl subjects (whose acquaintance with mechanical objects is admittedly less than that of boys) lends weight to the criticism that his tests depend on special knowledge rather than on a special aptitude.

Two years after Cox's work had been published (that is, in 1930) there appeared a most laborious study of mechanical ability carried out by Paterson, and his colleagues in America. The purpose of the experiment was two-fold: first to construct adequate tests of mechanical ability "...and second, to discover certain facts about mechanical ability itself—to determine whether it is an ability or group of abilities, how it is related to other psychological traits, to what degree it is susceptible to environmental influences, and how it is distributed in the population."[2]

In the preliminary try-out the investigators used, in addition to two standard group intelligence tests, 24 tests of mechanical ability namely, 8 simple motor tests, 2 balancing tests, 4 complex eye-hand co-ordination tests, 4 assembly tests involving manipulatlon and response to spatial relations; a test of mechanical knowledge and 5 other miscellaneous tests. The 7 tests of mechanical ability finally selected for the experiment proper in which 217 seventh and eighth grade boys were tested were : Card Sorting, Packing Blocks, Paper Form Board, Minnesota Spatial Relations, Steadiness, Stenquist Picture I and Minnesota Assembly; the two measures of intelligence included being Otis I.Q. and Otis M.A. The resulting data were treated by the correlational method and Spearman's tetrad-analysis criterion.

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[1] Rao, K. G. R. "Comparative Value of Certain Verbal and Non-Verbal (Primary Perceptual) Tests and Their Relation to Tests of Mechanical Ability," 1933, Ph.D. thesis in the London University Library.

[2] Paterson, D. G. et al., *Minnesota Ability Tests,* The University of Minnesota Press, Minnespolis, 1930, p. 32.

[For an interesting comparison between Cox's findings and the conclusions arrived at in the Minneaota investigation, see an article entitled "Mechanical 'Aptitude' or Mechanical 'Ability'? A study in method" by O. L. Harvey in J.Ed P., Vol. 22, 1931, pp. 517-522].

The most promising measures of mechanical ability as judged by their correlations particularly with the quality criterion[1] were the Minnesota Assembly Test, the Minnesota Spatial Relations Test and the Minnesota Form Board Test, the correlation coefficients for the three tests being .55, .53 and .52 respectively. Regarding the organization of mechanical ability, the investigators wrote : "The outstanding impression given by this material that the intercorrelations are low, leads to the presumption that specific factors rather than a single general factor characterise mechanical ability. Slight, but consistent, indications appeared that group factors might be present."[2] In the opinion of the present writer the reason for the high specificity of the mechanical factors found in this study lay mainly in the nature of the mechanical measures employed which were in many cases little different from tests of motor or manual functions. In this respect the research under consideration exercised a rather unfortunate influence on the subsequent American researches on mechanical ability for in most of them tests of motor and manual abilities have often been treated as valid measures of genuine mechanical ability.

The other relevant findings which the investigators reported were: uniqueness of mechanical ability with respect to intelligence ; lack of any signiflcant correspondence between mechanical ability and environmental conditions, the latter being judged from certain economic, cultural and mechanical considerations ;[3] and certain sex differences in favour of the boys, the last being interpreted as due more to the effects of previous practice in manipulating mechanisms than to any relevant consitutional differences

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[1] Three general criteria of mechanical ability were employed by the investigators, namely, quality, quality-quantity and information. Of these they considered the first to be the most suitable. (Paterson, D. G. et al., op. cit. pp. 199-202,)

[2] Paterson, D. G. et al., op. cit. p. 243.

[3] Thirteen measures such as, cultural status of the family, parent's education, mechanical operations of father etc. were employed to assess the cultural, economic and mechanical characteristics of the subject's environment.

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between the two sexes. The importance of these findings, however, is considerably weakened by the fact that no general factor of mechanical ability was discovered.

Koussy reported the findings of Edgerton's detailed two-factor analysis of the original Minnesota data. Edgerton suggested "...that by far the greater part of the correlations observed between the Minnesota tests is attibutable to 'g'; and that any remaining factor is conditioned largely by 'experience'."[1]

Spearman[2] also criticised the assumptions as well as the conclusions of the Minnesota investigation and tried to show that they contradicted one another.

In a study of the mechanical aptitude of 312 prisoners, Mars Simpson employsed the Stenquist Mechanical Aptitude Test (Form 1) which contains a series of pictures of common mechanical objects, the subject being required to determine which one of five pictures is related to each of five others. She found a correlation of .46 between mechanical aptitude and intelligence as measured by the Army Alpha Test which, according to her, suggested that mechanical aptitude as measured by the Stenquist Test was not unique in relation to intelligence. She questioned the evidence of Minnesota group of investigators thus: "When some investigators find a low correlation between a test of intelligence and a test of mechanical ability they conclude that they are measuring unique traits. Perhaps it would be more in keeping with actual fact to stress the unique tests themselves rather than the unique traits".[3]

In a centroid factorial study of certain mechanical ability tests Harrell gave a battery of 37 variables to 91 adult cotton mill machine fixers. The tests included the Minnesota battery of "mechanical ability" tests, the seven MacQuarrie tests of mechanical ability, O'Conner's Wiggly blocks, and the Stenquist picture-matching tests (the same as employed by Simpson in her preceding study). Five factors were isolated and interpreted as Perceptual, Verbal, Youth, Mental Agility and Spatial. The factorial structure of all the tests of mechanical ability except the MacQuarrie Dotting Test was satisfactorily accounted for by the two Perceptual and Spatial factors. (This is the first study reviewed so far in which the perceptual and spatial factors emerge separately; in most of the studies the two factors usually combine to form a unitary factor vaguely interpreted as space-

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1. Koussy, A.A.H. El. op. cit., p. 27.
2. Spearman, C. "What the theory of factors is *not*", J.Ed.P., vol. 22, 1931, pp. 112-117.
3. Simpson, R.M. "The mechanical aptitudes of 312 prisoners," J.App. P., Vol. 16, 1932, p. 493.

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perception). Perhaps a most significant finding of this experiment was "...that paper-and pencil tests measure each factor that has been measured by such cumbersome materials as the Minnesota assembly and spatial relations tests, and wiggly blocks. The latter two can be given only as individual tests, whereas all of the paper-and-pencil tests used may be given as group tests".[1]

Thompson[2] carried out an experimental invesigation in which he gave several tests of motor and mechanical abilities such as Block Counting, Cube Matching, the Minnesota Paper Form-Board, the Fine instrument test, etc. to senior and fresh-men classes of the Ohio State University College of Dentistry. The study was only partly designed to provide further evidence regarding the organization of motor and mechanical abilities into specific, group or general factors, the main object of the enquiry being to determine whether any of the factors obtained in the tests used showed significant correlation to success in different professional schools of a University. The average intercorrelations were found to be very low, providing no evidence for a factor common to all the tests. Thompson concluded in favour of the semi-specificity of ability in motor and mechanical performance.

Lastly, Goodman carried out an experiment to determine the factorial nature of mechanical ability as sampled by the MacQuarrie test of mechanical ability. This test consists of seven subtests, Tracing, Tapping, Dotting, Copying, Location Test, a test using blocks and a Pursuit test. He gave the MacQuarrie test to 329 radio assembly operators The resulting scores were correlated and later factorised by the centroid method. Three factors were isolated, two of which were identified as a space factor and a controlled manual movement factor respectively. The third factor was ambiguous but was tentatively identified as a Visual Inspection factor.[3]

To summarise the evidence on tests of mechanical ability, it seems necessary to divide such tests into two main kinds :

(a) Those in which the ability called for concerns essentially the understanding of mechanical problems whether presented materially as in the Stenquist assembly tests or visually as in Cox's diagrams of mechanical aptitude. The test-batteries employed by English

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1. Harrell. W. "A factor analysis of mechanical ability tests," Psychometrika, Vol. 5, 1940, p. 27.
2. Thompson, C. E. "Motor and mechanical abilities in professional schools", J. App. P., Vol. 26, 1942, pp. 24-37.
3. Goodman, C.H. "The MacQuarrie test for mechanical ability", J.App.P., Vol. 31, 1947, pp. 150-154.

investigators (Cox, Earle, Milner, etc.) have usually consisted of such tests.

(b) Those in which success seems to depend more on motor and manual dexterity than on any *genuinely mental ability*. Examples are Card Sorting, Packing Blocks, Tapping, Dotting and such other measures. The test-batteries employed by the American investigators (the Minnesota group of workers, Harrell, Thompson, Goodman, etc.) have often consisted exclusively or largely of such tests. It seems more appropriate to regard these tests as motor and manual tests rather than as tests of mechanical ability.

Evidence on tests of the first kind is conflicting; the findings of Cox, Earle and Milner broadly suggest that success in tests of mechanical ability calls for general intelligence as well as the ability to appreciate space-relations. Rao's work, however, gives no support to the spatial factor and seems definitely to contradict the interpretation of *m* given by Cox.

In researches on mechanical tests of the second type the factors often reported are either specific or group factors of a rather limited influence. This is a necessary consequence of the specific nature of most motor and manual abilities. Among the group factors reported in the various investigations the space-factor (factor of space-perception) seems to be the only one which has been frequently identified.

In general it might be concluded that since different investigators have employed different measures of mechanical ability, their findings are not strictly comparable. Nevertheless, the frequent appearance of a space-factor in many of the investigations suggests that if over and above general intelligence there is another common factor in such tests, its nature is very likely to be spatial.

Tests of Motor and Manual Abilities

In many of the mechanical jobs, the worker has not only to use his brains, but also the hands and other parts of the body; and in some jobs the motor or manual element is so predominant that no brains—at least not much mental ability—seems to be required. It is this that accounts for the general confusion between genuine mechanical ability, which seems to be essentially a function of the intellect and motor and manual abilities which on account of being largely independent of intellectual factors are really non-mental. The earliest test constructed to measure motor ability is the tapping test in which an unpractised subject is provided with a pencil and a piece of paper and the number of taps made by him per second recorded. McDougall's Plunger Test is another old test designed to measure manual ability and was much used in the earliest investigations. Its "...apparatus consists of a heavy brass plate with 24 raised sockets 2 centimetres high arranged in a circle. The subject has to insert a small steel plunger with a wooden handle into each socket as fast as he can; and the time taken to go completely round gives the score."[1] There are many other kinds of tests of motor and manual abilities which usually involve the use of mechanical apparatus.

In the following a brief account of some of the important researches on manual and motor abilities is given. The evidence strongly suggests that motor and manual performance is largely a matter of specific factors and that they are neither related to intellect nor to one another in any significant manner. A word might be said here about the distinction between the terms "motor" and "manual." The term motor is clearly more general and includes the manual. In practice, however, it is not very convenient to draw this distinction and consequently investigators have often used the two terms interchangeably. In what follows no attempt has been made to treat the evidence on these abilities separately. On account of the generally specific nature of the tests under consideration, a purely descriptive approach to this part of the enquiry could not be avoided.

One of the earliest investigations concerning the relationship between various motor abilities was that by Binet and Vaschide[2] (1897). They found a very low correlation between simple and choice reaction time, rate of tapping, and speed of running from which they concluded the relative independence of these functions.

Wissler (1901) gave a large number of motor and manual tests, such as accuracy of movement, perception of time, association, perception of size, etc. to Columbia freshmen and concluded "(1) Laboratory mental tests show little intercorrelation in the case of college students. (2) Physical tests show a general tendency to correlate among themselves, but only to a very slight degree with mental tests."[3]

Burt[4] in an enquiry which was chiefly designed to investigate the distribution and relation of educational abilities in the London

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1. Ballard, P.B., op. cit., pp. 198-199.
2. Summarised from an article entitled "A study of motor skill in the freehand duplication of geometrical figures" by W. A. Bousfield, J.App.P., Vol. 14, 1930, p. 478.
3. Wissler, C. "The correlation of mental and physical tests," Psychological Monographs 16, 1901. Quoted by Bousefield in the foregoing reference, p. 479.
4. Burt, C. *The Distribution and Relations of Educational Ability*, P. S. King and Son, Limited, London, 1917, pp. 58-59.

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school children also obtained some evidence on the relations between ability in different school subjects of the school curriculum. In a study of scores in various school subjects of a group of 120 children from the elementary schools of one of the Metropolitan boroughs in the North of London he found that the school subjects which were positively correlated fell into fairly distinct groups, namely, an arithmetical group, a manual group, a linguistic group and a composition group. In each of the 4 groups, a special ability was postulated over and above general intelligence in order to account for the correlational variations of the group concerned. The manual group of subjects in which the special manual ability seemed to be operative included Handwork, Drawing, Writing (quality) and Writing (speed).

Bradford[1] in a similar study of 224 school children, ages 9½ to 13½, found evidence for a special ability of motor co-ordination in writing and kindred manual operations Similar evidence for a special motor ability affecting writing, painting and needlework was also reported by Carey[2] from a study of the examination marks in different school subjects of about 600 children aged 7 to 14 years.

Perrin[3] gave 17 motor tests to 51 undergraduate subjects of the University of Texas. The tests were mostly of elementary motor functions : reaction time, aiming, tracing, tapping, steadiness, etc. The object of the investigation was to obtain evidence as to the nature of motor ability. Perrin found that the correlation coefficients between his tests were non-significant almost without exception, and concluded that motor ability was not general but somewhat definitely specialised. Muscio gave a number of motor tests such as aiming, tapping, tracing, a simple formboard, match insertion, etc. to 5 groups of male and female subjects varying from 12 to 20 in size. His results confirmed the findings of Perrin Muscio summed up : "(1) There is no 'motor type'. Terms such as 'motor dexterity' or 'practical ability' are misleading since a person's relative performance in any one motor test does not normally represent a general motor test performance level, that is a relative performance level which will be attained in any other motor test. (2) Motor capacities are relatively independent of intelligence For since motor tests do not correlate with one another positively to any appreciable degree, they cannot in general correlate positively with any other tests, and therefore not with intelligence tests".[3]

1,2. Mentioned by Burt in the preceding reference, p. 60.

3. Perrin F.A.C. "An Experimental study of motor ability," J.Ex.P., Vol. 4, 1921, pp, 24-56.

4. Muscio, B. op. cit. p. 184.

Garfiel[1] divided motor ability into the following 5 elements: speed of voluntary movement, accuracy of voluntary movement, control of voluntary movement, strength of voluntary movement and motor adaptability. She gave a battery of motor tests designed to measure these five aspects of motor ability to 50 college girls. She found that the intercorrelations of the motor tests varied from .15 to .25 while the correlation of the battery with the ratings of the ability of the subjects by three judges was .77. She wrote "...motor ability.. represents a group of abilities in the main, independent of, or at least different from mental ability".[3] Cowdry, however, in an sttempt to refine Garfiel's tests found evidence contrary to that of the latter and suggested that "The interrelationships found raise definite doubt as to the existence of a distinct motor ability whose co-ordinated expression is relatively independent of general intelligence".[3]

Farmer gave three aestheto-kinetic[4] tests—a term which he prefers to 'motor tests'—to several groups of varying sizes. The tests were: The Choice Reaction Test, the McDougall Schuster Dotting Test and the Pursuit Meter. The average correlation coefficient between the three tests was only .22 but "the consistency shown between the intercorrelations in the various groups and the number of subjects tested make it significant".[5] Discussing the earlier findings of Perrin and Muscio, Farmer suggested that certain considerations such as the diversity of the motor tests employed and the fewness of the subjects tested cast doubt upon the significance of the results obtained by his predecessors. He wrote: "They arrived at the conclusion that there was no general motor factor. I have not arrived that there is such a factor, but merely that certain motor tests which I have called aestheto-kinetic tests intercorrelate consistently with each other and with certain other tests, and therefore I draw the conclusion that these tests have some element in common".[6]

Bousfield[7] gave a motor test of 12 parts which required freehand duplication of geometrical figures consisting of simple curves and straight lines to 180 children of the fourth, fifth and sixth grades. The test yielded a very low correlation (.180±.069) with the intelligence scores made by the children on the Otis Classification Test. Bousfield concluded that the function in question was relatively independent of the measure of intelligence used.

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[1] Garfiel, E. "The measuement of motor ability", Archives of Psychology, 62, 1923, p. 47.

[2] Ibid., p. 44

[3] Cowdry, K.M. "A note on the measurement of motor ability", J.Ed.P., Vol 15, p. 519.

[4] According to Farmer the term motor is too wide and must include all tests involving movement. By aestheto-kinetic tests he meant "a special group af motor tests which have the common characteristic that afferent impulses received through sensory organs have to be interpreted as signs for the performance of certain rapid and accurate movements". For reference see below.

[5] Farmer, E. "A group factor in sensory-motor tests", B.J.P., Vol. 17, 1927, p. 328.

[6] Ibid., p. 329.

[7] Bousfield, W.A. "A study of motor skill in the free hand duplication of geometricai figures," J App.P., Vol, 14, 1930, pp. 478-385.

Crockett distinguished between three senses of the term mechanical abilty :

(a) Mechanical intelligence in the sense of inventiveness or mechanical insight (spatial thinking).

(b) Motor ability—any single motor task and as a relatively simple function.

(c) Manual ability as "expertness or grace in manual tests" and as a complex or general function. He further devised a mechanical apparatus as a measure of manual ability. His test correlated with intelligence .4±.09 for 87 persons; the correlation with schooling being .14±.04, for 250 subjects and correlation with age being .16±.04 for 250 subjects and the correlation with the Detroit Mechanical Aptitude Test being .31±.07 for 83 persons. From these results he concluded that manual ability (in the third sense of the term) was relatively unrelated to age, schooling and intelligence and that since the reliability and validity of the measures of manual ability were fairly high, the function involved appeared to have the characteristics of a distinct trait "...having for its basis the organization and functional activity of the nervous system".[1]

A very thoroughgoing research on the nature and measurement of manual abilities was carried out by Earle and Gaw with the assistance of other members of the staff of the National Institute of Industrial Psychology, London. The authors distinguished two main factors required in various manual tasks, namely speed of movement and accuracy of movement giving the following three elements of manual dexterity.

(a) "Speed of movement the prime consideration—the accuracy of the movement being independent of the operation ;" as for example in the tapping movement of forefinger only.

(b) "Speed of movement moderated by the need for accuracy in control;" as for example in placing pegs in holes in a board.

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[1] Crockett, A.C. "A measure of maunal ability", J.App. P., Vol. 14, 1930, p. 425.

(c) "Accuracy of movement most important—speed of movement being subsidiary"; as for example in aiming accurately at points equally spaced along a line drawn on a sheet of paper placed horizontally.

Fourteen different tests of manual dexterity designed to measure the above three aspects of manual dexterity were given to several groups of elementary school boys and girls. The test intercorrelations were positive in most cases but were of a low order indicating that the factors involved in various manual tests were largely specific. There was also some evidence (although meagre) for two group factors – one of speed and the other of accuracy. To report the conclusions in the words of the investigators: "The study of the intercorrelations of the tests brings out quite clearly the very high degree of *independence* of the abilities measured by them. The factors which principally determine success in each test are *specific* to the test situation.

"When Spearman's tetrad-difference criterion is applied to the tables of correlations in order to discover the presence or absence of group factors, the results conform to the general situation when, according to Spearman, there are no group factors.

"But the curious fact that the tests may be grouped...to show higher correlation between themselves than with tests of other groups might be taken to signify the *presence*, rather than the absence, of group factors. In such an event, it is suggested that these might be factors of speed and accuracy respectively."[1]

In a later investigation Cox[2] employed a number of 'mechanical' assembling and 'routine' assembling tests such as the Porcelain Test, Wiring Test, etc. He gave these tests along with certain other tests of mechanical aptitude to several groups of adult subjects and elementary school boys and girls. He found that success in manual operations was partly ascribable to *g*, partly to *m* (mechanical aptitude), but also partly to a group factor of manual dexterity and another *specific dexterity factor*. In routine tasks such as various assembling and packing jobs, the importance of *g* and *m* was practically insignificant; the factors that mattered most were the group manual dexterity factor and the specific dexterity factor. In mechanical tasks requiring solution of problems as to how the parts of a given mechanism must be assembled, *g* and *m* were more important, the latter being even more important than the former. In simple tasks calling for elementary motor skill, the factors involved were mostly specific.

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[1] *The National Institute of Industrial Psychology, Report 4,* 1930, pp. 87-88.

[2] Cox, J. W. *Manual Skill, Its Organisation and Development,* Cambridge, at the University Press, 1934.

Goodenough and Smart[1] studied the question as to whether there is a general motor ability in young children. They applied 6 motor tests (finger tapping, stylus tapping, three-hole test, needle threading, simple reaction, and a walking path test) to 154 children divided into four groups, so selected as to give a minimum age range within each group. All children were tested at the period midway between their annual birthday, that is, at ages 2½, 3½, 4½ and 5½. The intercorrelations between the various tests for each of the four age-groups were factorised by the Thurstone method. The first factor which was common to all the tests and was reported to be fairly constant in the different age-groups, was interpreted as 'general motor-maturity'. The second factor which had a number of approximately zero loadings and which was also less constant was interpretted as "attentiveness." A third factor was also isolated but the loading was small enough to be attributable to chance. Altogether the evidence was interpreted by the investigators as indicating the presence of a general motor factor.

Lastly, in a factorial study of motor abilities Buxton[2] applied a battery of 13 motor tests (4 Gain Tests, Thrusting Steadiness, Stationary Steadiness, Triple Tapping, Cube-Packing, Spool-Packing, 2-Bar Packing, Wrist-turn Tapping, Motility Rotor and Pursuit Rotor) to 76 boys between the ages of 12 and 16. The correlation matrix was analysed by the centroid method and 6 factors extracted. After rotation the tentative interpretation of the factors offered was : Manipulative performance, Spatial perception, Steadiness, Specific manipulative type of educability, and Co-ordination of muscle groups in producing spatial patterns. He found no evidence for a general motor ability.

To summarise the evidence on tests of motor and manual abilities, it may be convenient to consider the researches reviewed under three heads :

(1) Researches that are mostly or partly devoted to a consideration of the relationship between general intelligence on the one hand and motor or manual abilities on the other.

(2) Researches that are mostly or partly concerned with the determination of the nature and organisation of motor and manual abilities. These again fall into two sub-groups.

(a) Those that emphasise the specificity of the factors involved.

(b) Those that also give evidence for general factors.

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1. Goodenough, F.L., and Smart, R. C. "Interrelationships of motor abilities in young children," Child Development, 6, 1935, pp. 141-153.
2. Buxton, C. "The application of multiple factorial methods to the study of motor abilities," Psychometrika, Vol. 3, 1938, p. 86-93.

The researches falling under the first head are those carried out by Wissler, Garfiel, Bousfield and Crockett; and they all deny any significant relationship between intelligence and motor performance. Since however, the subjects in all these studies were either children of school age or adults, the conclusion should not be extended to very young children in whose case many investigators have reported a significant relationship between the variables in question. The only investigator mentioned in this review who reported a positive correlation between intelligence and manual ability is Cox; but he also makes it plain that this relationship obtains only in the case of mechanical problems calling for manual skill as well as mechanical insight Since this is tantamount to saying that the problems in question are not pure tests of manual skill, Cox's evidence does not really contradict the findings of other investigators.

The researches emphasising the specificity of motor or manual abilities are those carried out by Binet and Vaschide, Perrin, Muscio, Garfiel and by Earle and Gaw—these constitute a clear majority and in the opinion of the writer also seem to enshrine most of the truth about the matter.

Among the last group of researches which contain suggestions in favour of the possible existence of a general motor or manual factor are those reported by Burt, Bradford, Carey, Farmer, Earle and Gaw, Cox, and Goodenough and Smart.[1] The evidence provided by Burt, Bradford and Carey is based upon considerations of performance of children in a certain group of school subjects supposed to call for manual skill. Since, however, the activities pertaining to the manual group of school subjects are likely to be rather complex and, therefore, not entirely valid measures of the ability concerned, their findings can at best be treated as useful hints or suggestions for further research and not as established facts. In fact there is already evidence that what Burt and others once considered a unitary manual ability consists of "...a number of more obscure sub-factors—e.g., a factor of visual space-perception and imagery, factors for the co-ordination of the finer and coarser muscles, and a kinaesthetic factor possibly entering into both."[2] Farmer's evidence is emphasised by him not so much to establish the claim for the existence of a general motor factor as to question some of the generalisations of his predecessors (Perrin, Muscio etc.) and cannot, therefore, be taken too seriously. Earle and Gaw's evidence also is more pertinent to stressing the specificity of manual abilities than to establishing the existence of some group manual factor or factors. Cox's evidence for a group factor of manual dexterity is more difficult to interpret; even if its existence is granted, its influence as compared to that of *g*, *m* or the specific factors concerned seems to be rather restricted. In any case, there is need for further confirmation of his results by more advanced factorial techniques The evidence of Goodenough and Smart also should be interpreted with caution. For children of very young age as were employed by these two investigators, the performance of even relatively simple bodily movements, which at a later age may become perfectly habitual, may often require a certain degree of intelligence and for that age, therefore, may not be so simple a matter as adults are sometimes inclined to think. It is probable, therefore, that the general factor isolated by these investigators instead of being valid evidence for a general motor function was really due to general intelligence required in attending to the different test-tasks. If in the battery of motor tests employed in the research a measure of general intelligence had also been included, the explanation suggested by the present writer would possibly have been supported.

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[1] Buxton's name has not been included since he definitely stated that in his factorial research there was no evidence for a general factor.

[2] Burt, C. "Symposium on the selection of pupils for different types of secondary schools, 1.—A general survey," B.J.E P., Vol. 17, 1947, p. 60.

To sum up, the evidence for the existence of a group motor or manual dexerity factor is reported by a number of investigators, but the evidence does not seem to be conclusive. Even if its existence is granted, its influence appears to be very much restricted as compared to the influence of specific factors involved in doing manual tasks.

Group Tests of Space-Perception

A brief indication of the origin and nature of tests of space-perception was given on page 5. A few words regarding the origin and development of non-verbal group tests of which the tests in question are perhaps the most important kind, also seem necessary.

The need for constructing a suitable non-verbal group scale of intelligence first became pressing when the American army psychologists during the great war of 1914-1918 were confronted with the question of measuring the intelligence of recruits in the American army. The problem for testing the literate recruits was solved by constructing a group verbal test of intelligence, since known as the "Army Alpha Examination." This scale, however, was unsuitable for the illiterate sections of the army as well as for those whose familiarity with English was not of the required standard. Nor was it feasible to use the available performance tests for estimating the intelligence of the illiterate and semi-literate subjects, on account of the time expenditure involved in their administration. The army psychologists overcame this difficulty by constructing from the various non-verbal tests which had been previously devised and experimented with, by Norsworthy, Knox, Porteus, Dearborn, Pintner and others, a composite scale of intelligence, the directions for which could be given by gesture and the execution of which required no acquaintance with the spoken or written language. This scale known as the "Army Beta Examination" consisted of 7 tests, Maze, Cube Analysis, X-O Series, Digit-symbol, Number Checking, Pictorial completion and Geometrical construction.[1] Several other non-verbal group tests of intelligence were devised by different workers soon after, among which may be mentioned Thorndike's 'Group Examination of Intelligence Independent of Language',[2] Pintner's 'Non-Language Group Intelligence Test'[3] and Dodd's 'The International Group Scale.'[4] At present quite a number of non-verbal group tests are in use and research has shown that the abilities they sample need not in all cases be the same as general intelligence, particularly in the case of non-verbal group tests employing fundaments of a spatial nature such as the Form Relations Test of the National Institute of Industrial Psychology. Since the reasons why group tests of space-perception are regarded as particularly valid measures of practical ability have already been stated, it is time to pass to a consideration of the important researches conducted on these tests with a view to examining the nature of factors involved in such tests. Before beginning to describe these, however, a research by Davey[5] on non-verbal pictorial tests of intelligence may be mentioned. She undertook a comparison of group verbal and pictorial tests of intelligence in order to test the accuracy of Thorndike's statement that "...the ability measured by verbal tests is not the same as the ability measured by non-verbal tests..."[6] The pictorial items of the non-verbal group tests were carefully designed to match closely the items of the verbal measures. For example, her verbal selections test included the words: trumpet violin table dream, and was balanced in the non-verbal test by drawings of a trumpet, violin, etc. Examining the correlational data arising from giving the tests to 243 children, Davey found evidence only for a general factor present throughout, there being no indication of an additional language or pictorial factor.

Early tests of space-perception involving discrimination of lengths, bisection and trisection of lines etc. as used in their researches by Burt,[1] Brown,[2] Ableson[3] and others showed positive correlation with *g*. McDougall's[4] more complex Dotting Text also yielded high correlation co-efficients with general intelligence. Very high correlation between his tests and *g* was also reported by Line[5] whose work was specifically designed to study the growth of visual perception in children. A primary object in constructing his test material was to eliminate as far as possible the influence of the past experience of the subjects from the test situation. Line employed two-dimensional space-diagrams, some of them being coloured or having different degrees of brightness. In this he followed Spearman who first suggested the theory that the only factors absolutely independent of experience were space, brightness and colour. The subjects were first shown 3 diagrams exemplifying the 'right' cards and three the 'wrong' cards from a mixed assembly of unsorted cards. The tests were found to correlate very highly with *g* and were recommended by Line as very valuable measures of intelligence—a most important consideration bėing their independence of past experience.

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[1] See *Mental Tests in the American Army* by C. S. Yoakum, and R. M. Yerkes, Sidgwick and Jackson, London, 1920, pp. 79-92.

[2] Thorndike, E.L. "A standardised group examination of intelligence independent of language," J. App. P., Vol. 3, 1919, pp. 13-32.

[3] Pintner, R. "A non-language group intelligence test," J.App.P., Vol. 3, 1919, pp. 199-214.

[4] Dodd, S.C. *International Group Mental Tests*, Princeton, 1926.

[5] Davey, C.M. "A comparison of group verbal and pictorial tests of intelligence," B.J.P., Vol. 17, 1926, pp. 27-48.

[6] Thorndike, E.L. "Intelligence and its measurement: A symposium, I." J.Ed.P., Vol. 12, 1921, p. 126.

A work similar to Line's but whose main object was not the study of space-perception but the construction of good measures of general intelligence was that of Fortes.[6] In order to eliminate as far as possible the effect of past experience on test scores he employed as fundaments in his tests two-dimensional meaningless diagrams. A tetrad-analysis of the statistical data arising from giving his tests to 221 subjects revealed only *g* running through all the tests used; there being no evidence for any other group factor such as a spatial factor.

The first factorial research in which indications of a spatial factor were found was that conducted by Kelley.[7] He tested a group of 140 children (boys and girls together) with an average age of 13, and another group of 60 children with an average age of 9. Analysing the data of the two groups by his own method of analysis, Kelley reported evidence for a general and a verbal

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1. Burt, C. "Fxperimental tests of general intelligence," B.J.P., Vol. 3, 1909, pp. 94-177
2. Brown, W. "Some experimental results in the correlation of mental abilities," B J.P., Vol. 3, 1910, pp. 296-322.
3. Abelson, A.B. "The measurement of mental ability of 'backward' children," B.J.P., Vol. 4, 1911, pp 268-314.
4. Spearman, C. *The Abilities of Man*, p. 341.
5. Line, W. "The Growth of Visual Perception in Children", B.J.P., Mon. Supp 15, 1931.
6. Fortes, M. "A New Application of the Theory of Nœgenesis to the Problem of Mental Testing", 1930, Ph.D. thesis in the London University Library.
7. Kelley, T. L. *Cross roads in the Mind of Man*, Stanford University Press, Stanford, 1928, pp. 97-140.

factor. In addition to these factors, Kelley also observed a specificiality between two tests which according to him involved the 'manipulation of spatial relationships'—the two tests being Speed of Reading and Memory Symbols. Curiously enough the specificiality also showed itself in an Arithmetic power test, a fact which cannot be explained in spatial terms. (A similar specificiality was also reported later by Smith.[1] But whether the phenomenon was due to a spatial factor or to some other possibility, was not clear). Kelley's work is of special importance since it seems to support the claim that both verbal and spatial judgments are measurable at an early age.

Brown and Stephenson[2] gave to 300 boys aged 10 to 10½ years, 19 tests of which 10 were perceptual involving space relations; the object of the enquiry being to contribute further evidence on Spearman's two factor theory. The distributions were approximately normal in all cases, but in order to obviate any disturbances in tetrads attributable to the non-normality of distributions, the scores were normalised before being correlated. A verbal factor was recognised and partialled out; a specificiality between two spatial tests—Fitting Shapes (a paper Formboard test) and Dot pattern Perception—was also observed and partialled out; all the tetrad differences of the residual correlations were computed. The authors concluded that the evidence supported the two-factor theory of Spearman.[3]

The original correlational data of the Brown and Stephenson study as these existed prior to the partialling out of the influence of the verbal factor and the Code Specificiality, were recently subjected to a multiple-factor analysis by Robert Blakey.[4] Five factors were extracted and rotated into a fairly simple structure. The interpretations offered for four of the five factors were: Verbal, Spatial (calling for visual or spatial imagery), Perceptual, Speed and a general factor possibly due to maturation. Blakey considered that owing to the statistical superiority of the multiple factor techniques over the two-factor method, his results which were in close agreement with the reported findings of many other investigators such as Thurstone, Garrett and Wright, offered a better interpretation of facts than the conclusions of the original authors of the study.

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1. Smith, G.M. "Groupfactors in mental tests similar in material or in structure," Archives of Psychology, 156, 1933.
2. Brown, W., and Stephenson, W. "A test of the theory of two factors," B.J.P., Vol. 23, 1933, pp. 352-370.
3. This conclusion was vehemently criticised by Godfrey Thomson on certain methodological grounds. See Thomson's "Note on Dr. William Brown's paper on a central intellective factor", B.J.P, Vol. 23, 1933, p. 404.
4. Blakey, R. "A re-analysis of a test of the theory of two factors", Psychometrika, Vol. 5, 1940, pp. 121-136.

The specificiality between their two spatial tests reported by Brown and Stephenson which further seemed to extend into three other tests, all of which were spatial, however, raised a problem as to whether there was or was not a group factor of spatiality necessary to account for the observed phenomenon. Koussy's well-known research on tests of space-perception was planned to investigate this question. Before passing to Koussy, it may be mentioned that in an investigation slightly earlier than the Brown Stephenson study, Stephenson[1] had used verbal subtests along with non-verbal sub-tests in a very detailed tetrad analysis. He found that the verbal subtests showed the presence of a group factor other than *g*, which he called '*v*', meaning the verbal factor, while the non-verbal tests showed the presence of *g* only.

Koussy applied 28 tests to 162 central school boys ranging in age from 11 to 13 years. Of tests used, 15 were spatial and such as involved the appreciation of "area" in one way or another. A careful analysis of the intercorrelations using the 8 *g* tests as reference values revealed that there was no spatial factor covering all the spatial tests but that there were definite indications of a group factor common to the following 8 tests—Memory for Designs, Form Relations, Fitting Shapes, Equation A (Selective), Pattern Perception, Spatial Analogies, Band Completion and Correlate Eduction A (Inverse Drawing). The average specific intercorrelation between the 8 tests was .272, with a standard deviation of .075; the probable error for zero specific correlation being .053. Koussy labelled the group factor in question '*k*' and in view of the special nature of the 8 *k* tests and the introspective evidence provided by certain carefully chosen children and adult subjects suggested that his *k* factor signified the ability "to obtain, manipulate and utilise visual spatial imagery".[2]

In an investigation which was carried out earlier than Koussy's research but the factorial analysis of whose results was not completed till recently, Smith[3] confirmed the evidence of Koussy's experiment regarding the existence of a group factor in certain spatial tests. He gave 11 tests (some verbal and some spatial), 6 of which were identical in principle but not in individual items included, with some of the tests studied by Koussy, to 100 children from a Scottish secondary school, ranging in age from 12½ to 14½. When the influnce of *g* was partialled out of the 630 tetrads, 11 were found to exceed 5 times their probable error. A further examination of the data by Burt's Group-Factor method and Holzinger's Bifactor Technique confirmed the hypothesis that there was a spatial group factor super-imposed on the general factor in the spatial tests. Using one of Spearman's formulas for obtaining the spatial factor saturations for the spatial tests, he found a very close agreement between Koussy's *k* saturations and his own for the six tests common to both the investigations.

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[1] The following three articles by W. Stephenson, J.Ed.P., Vol. 22, 1931.

1. "Tetrad-differences for non-verbal subtests", pp. 167-185
2. "Tetrad-differences for verbal subtests", pp. 255-267
3. "Tetrad-differences for verbal subtests relative to non-verbal subtests", pp. 334-350.

[2] Koussy, A.A.H.El. op. cit., p. 86.

[3] Smith, I.M. "Measuring spatial ability in school pupils", Occup.P., Vol. 22, 1948, pp. 150-159.

In an experiment which was partly designed as an extension of Koussy's research and partly as an investigation into the range and nature of factors present in a wide variety of perceptual tests, Clarke[1] gave 29 tests which included all the 8 *k* tests of Koussy and many other perceptual tests of a different kind (involving the manipulation of lines, the appreciation of Gestaltens etc.) to 202 girls from 3 schools, a senior school, an unselective central school, and a residential school of the senior school type. An analysis of the correlational data by the Spearman technique as well as Thurstone's Centre of Gravity method revealed only one general factor which accounted for almost all the correlational variations found in the data. This appeared to contradict Koussy's findings. Clarke suggested two alternative explanations for the apparent discrepancies between the results of the two researches: either Koussy's *k* was merely symptomatic of the differential training and past experiences of subjects of the male sex as distinguished from the female, or the factor in question might have split up into two or more minor factors in his own investigation, some evidence for which was found in the form of a group factor of small significance amongst tests of visual imagery but which did not show any overlap into the spatial tests.[2] Of these he thought the former to be more probable of the two. Clarke concluded: "In general our main findings are extremely pertinent for Spearman's theory of g-factor. Over the wide range of tests we have used, g-factor alone can account for almost all our findings. Moreover, if on further work our results, rather than Koussy's, are verified, the facts will be of considerable importance in factor-analysis. A primary space factor, of wide range, covering a large number of non-verbal tests at present being used as intelligence tests (to replace verbal intelligence tests, on the ground that these involve 'v' as well as 'g'), would bring a new feature into mental measurement. At present there is no compelling evidence for such a factor—even if we allow for Koussy's work. Spatial tests do not, apparetly, involve a factor over and above the universal factor 'g' of Spearman. We can still continue to use such tests as reference tests of 'g', as the 'purest' measures of 'g' at present known."[1]

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[1] Clarke, G. "The Range and Nature of the Factors in Perceptual Tests," 1937, Ph.D. thesis in the University of London Library.

[2] Clarke also found some evidence for a verbal group factor common to his verbal tests, but again it was not so significant as it might have been expected.

Thurstone[2] gave a large battery of 56 variables designed to include abstraction, space, visualising, form, number, reasoning and verbal material to 218 subjects of age 16 and upwards. The resulting correlation matrix was analysed by his own technique and 12 factors extracted. The factors were further rotated with considerable labour into a 'positive orthogonal manifold.' Seven of the 12 factors were interpreted as : the verbal factor 'V', the number factor 'N', the space factor 'S' the memory factor 'M', the perceptual factor 'P', the word factor 'W', and the induction factor 'I'. The interpretation of the first 4 factors (V,N,S,M) was very clear, the identification of the last 3 (P,W,I) was relatively uncertain. In a slightly later investigation[3] which was partly designed to make a special study of the perceptual factor (P) whose interpretation in the earlier experiment was not so definite and partly to confirm the earlier results, Thurstone used all the 56 test-variables of the first study and included many more among which were 9 new tests supposed to depend on the perceptual factor. The findings of this research gave full confirmation to the earlier results since all the earlier factors reappeared in the latter work and also established the uniqueness of the perceptual factor. It should be noted that the space and perceptual factors are separate and not identical—a finding similar to that of Harrell whose experiment was summaried earlier on p. 21. This raises the question as to whether the group factor of space-perception as identified by Koussy and others is a unitary factor or consists of two components– a space factor and a perceptual factor. It is difficult to settle the point on the basis of evidence available. (In subsequent discussions it is assumed that the space and perceptual factors as identified by Harrell and Thurstone are identical with each other and with the group factor of space-perception as reported by Kelley and other investigators).

Lastly, Woodrow[4] reported the results of giving a large battery of 52 variables to 110 adult subjects (median age 19.9 years). Included in the battery were also tests of social intelligence, certain attainment tests and Seashore's test of musical ability. The centroid method of factor analysis was adopted and after rotation the factors identified were these: Verbal ability, Spatial ability, Attention, Musical ability and Memory. The spatial factor had also a considerable loading (.693) in the Verbal Analogies test—a puzzle which Woodrow tried to explain by mentioning an earlier case in which another investigator Thurstone) had also in a similar study obtained a high spatial loading in his verbal classification test which according to the latter was to be interpreted as due to the helpfulness of visual imagery in the test performance.

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[1] Clarke, G. op. cit., pp. 156-157.

[2] Thurstone, L. L. *Primary Mental Abilities*, The University of Chicago Press, Chicago, 1938.

[3] Thurstone, L.L. "The perceptual factor," Psychometrika, Vol. 3, 1938, pp. 1-18.

[4] Woodrow, H. "The common factors in fifty-two mental tests", Psychometrika, Vol. 4, 1939, pp. 99-108.

To summarise: the evidence on group tests of space perception is again not entirely concordant. On the one hand are the researches of Line, Fortes, Brown and Stephenson and Clarke which suggest that all or most of what these tests measure is general intelligence; on the other hand are the investigations of Kelley, Blakey, Koussy, Smith, Thurstone and Woodrow which suggest that spatial group tests in addition to measuring intelligence also involve a group factor generally to be interpreted in terms of visuo-spatial imagery. Since, however, the factorial techniques employed in most of the latter group of researches are statistically of a more advanced nature than Spearman's tetrad-analysis methods used in most of the former group of researches, it may be concluded with some confidence that group tests of space-perception, in addition to being very effective measures of general intelligence, also sample another ability requiring facility in visuo-spatial imagery.

Altogether, then, in researches on three[1] of the four important kinds of tests of practical ability, namely, performance tests, tests of mechanical ability and group tests of space-perception, evidence has been collected for the presence of group factors whose psychological nature has been often interpreted by the investigators concerned in spatial terms.[2] This raises an important issue: Are the group factors for which evidence was found in these three apparently different kinds of tests the same or not? The next chapter addresses itself to a discussion of this question.

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[1] The group factors of space-perception or of some other kind occassionally reported in studies on motor and manual tests (for example in the investigation by Buxton summarised on page 29) do not deserve any serious consideration owing to their admittedly restricted nature.

[2] Some of the specifie terms used by the various authors being, Form perception, Appreciation of spatial relations, Recognition and manipulation of shapes, Facility in spatial and visual imagery etc.

CHAPTER III

Relationship between Practical Factors, F, *m* and *k*

ARE the the group factors for which evidence was separately found in researches using performance tests, tests of mechanical ability and group tests of space perception the same or different ? Apart from the striking similarity of the interpretations provided by their authors for the factors concerned, which strongly suggests that the factors are similar in their psychological characteristics, are there any investigations conducted specifically to determine experimentally the relationship between these factors ? If so, what is their evidence ?

Before presenting the relevant data, it may be pointed out that since the investigators who have specially interested themselves in this problem are all British with the sole exception of one[1] who also conducted his research in an English university, this controversy concerning the group factors in three different kinds of tests has been arbitrarily, but quite profitably, narrowed down by them to the question of clearing the position between the three group factors F, *m* and *k*[2]. F is taken to represent the common group factor in performance tests, *m* to represent the factor in tests of mechanical ability and *k* to designate the factor in group tests of space perception. It is important to note that F, *m* and *k* are no longer special factors belonging to certain special tests used by certain individual authors ; they now represent the respective group factors in three different areas of practical ability—corresponding to the three kinds of measures employed in studying that function. The question which the researches to be described now have partly or wholly addressed themselves to answering is, broadly speaking, this : Are F, *m* and *k* identical in their psychological nature or not ? If they are, it follows that the investigations in which different kinds of tests of practical ability have been thrown together, evidence must be forthcoming for a group factor common to all such tests, irrespective of whether a given test is of the performance type, or the mechanical ability type or the space-perception type—assuming that there is evidence for at least one group factor over and above the general factor of intelligence. On the other hand, if the three factors under discussion are not the same, such evidence should fail to show itself. Since different combinations of tests of practical ability have been employed in different investigations, it is desirable, for purposes of treatment, to group the researches according to the combinations used. Theoretically, 4 test combinations are possible, namely,

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[1] Koussy, who did his work at the London University.

[2] It will be recalled that these three letters were first used by Alexander, Cox and Koussy to designate the group factors found common to their performance tests, tests of mechanical aptitude and tests of space-perception respectively.

(i) F (performance), *m* (mechanical ability) and *k* (spatial) tests.

(ii) F and *m* tests.

(iii) *m* and *k* tests.

(iv) F and *k* tests.

There being no investigation exemplifying the first combination (employing all the three kinds of tests), it is proposed to summarise the relevant researches in order of the remaining three combinations.

Relationship between F and m

As was mentioned earlier on page 15, Alexander used 3 of Cox's *m* tests (Mechanical Explanation, Mechanical Completion and Mechanical Diagram) on three of his groups with a view to exploring any possible relationship that might manifest itself between the ability measured by performance tests and *m*. His results were conflicting. With the first group (100 Scottish pupils, mean age 11 years, 10 months) they appeared to measure general intelligence only. With the second group (71 boys, mean age 15 years, 11 months), they appeared to call for a special ability which was different not only from general intelligence and verbal ability but also from F—the practical factor. Slater[1] suggested that this difference between the younger and older groups was campatible with the view that *m* tests depended more on special knowledge than on any special aptitude. With the third group (102 boys, mcan age 16 years, 11 months) the tests measured both *g* and F.

As far as the present writer is aware there is no other investigation bearing on the F-*m* combination of tests.

Relationship between m and k

Two *m* tests (Mechanical Explanation and Mechanical Completion) were also used by Koussy in his investigation summarised on page 35. He found that the correlation between these two tests could be analysed in terms of general intelligence and a very slight degree of spatial ability, there being no need to postulate the existence of any special mechanical factor.

In a study designed mainly to determine the general selective value of certain new tests of spatial judgment in engineering work, Holliday gave a battery of 10 tests (some newly constructed and some of old standing) all of which were intended to measure abilities needed in different kinds of skilled manual work. The tests, in addition to a verbal test of intelligence (N.I.I.P. Group Test 33) were these: Cox's Mechanical Models M_1, Vincent's Mechanical Models, Space Perception 1 & 4 (Manipulation), Form Relations, Squares, Perception 2 & 3 (Recognition), Recognition of Designs, Figure Construction, Parallel Lines and Divided Lines. The test population consisted of 89 apprentices in an engineering firm. The resulting correlational data were factorised by Slater using Thurstone's method. The conclusion relevant to the present purpose was: "The data provide no evidence in support of the hypothesis that there is a special 'mechanical abilitv' which can be differentiated both from general intelligence and spatial judgment. The residual correlations between Vincent's Models and Cox's Models after *g* and *k* are partialled out is .076. 'Mechanical ability' as measured by these two tests appears therefore to depend almost entirely on general intelligence and spatial judgment".[1]

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[1] Slater, P., "Some group tests of spatial judgment or practical ability", Occup. P., Vol. 14, 1940, p. 44.

Kerr[2] made a factorial study of the results obtained by correlating 4 different kinds of tests (1. Verbal Intelligence, Otis Quick Scoring Mental Ability Test; 2. Practical Intelligence—spatial jndgment—Form Relations; 3. Mechanical aptitude—Boys only—Cox Mechanical Aptitude Tests, M. 1 and 11; and 4. Clerical Ability—Girls only—N.I.I.P. Test 20) with one another and certain school subjects (English, Geometry, Algebra, Arithmetic, Language, Science and Art). His population consisted of 495 pupils (boys and girls) at a mixed Scottish secondary school. Three factors were isolated and interpreted as *g*, a bipolar Educational vs. Practical factor and another bipolar Non-Verbal vs. Verbal. The factorial structure of the mechanical and the practical tests was almost identical[3] in all the three factors indicating that the mechanical and practical (spatial) factors were not different.

Lastly, Shuttleworth gave a battery of 16 tests consisting of 3 mechanical tests (Cox test, M. 1, Cox test E. 1 and Vincent Models test A), 7 tests of spatial judgment and form relations (such as Space Perception Test, Form Relations Test, Designs—reproduction etc.), 3 tests of hand and eye co-ordination and manual dexterity; two group intelligence tests; and a clerical test to 109 junior technical school boys aged between 13 and 14 years. The main purpose of the research was to construct a

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[1] Slater, P. op. cit., p. 53.

[2] Kerr, G. "Aptitude testing for secondary courses", Ooccup. P., Vol, 16, 1942, pp. 73-78.

[3] The actual loadings were:

	I	II	III
Spatial	.40	—.49	.17
Mechanical	.48	—.38	.14

suitable technical aptitude battery for use with entrants to junior technical schools. As a matter of interest, Shuttleworth factorised his correlational data by the centroid method and extracted two significant factors. Whatever the interpretation of the factors, assuming that one of them is general (which of course is not in accordance with Shuttleworth's own interpretation),[1] the negative inference to be drawn from the study is apparent, namely, that this experiment too provides no support to the separate existence of the mechanical and spatial factors.

Relationship between F and k

Price in a study conducted to determine the relationship between F and *k* gave 3 verbal tests of intelligence, 5 performance tests (including Alexander's Passalong and Kohs' Block Design) to 85 University men students all between the ages of 19 and 22 years. The correlational data were examined by the Spearman and Thurstone methods separately. Both techniques gave consistent results in indicating that the *k* factor in the space-perception test was the same as the F factor in the performance tests. Price concluded, "...It is recognised, of course, that something intrinsic to performance, might be crticical for children, for our students, however, there would seem to be nothing critical in the performance as such".[2]

Bradford carried out an investigation on the 105 new entrants of a certain junior technical school (13 to 14 years of age) to compare among other things the efficiency of a performance battery of 4 tests and a specially constructed group test in indicating the likelihood of progress to be shown by the pupils at the end of the first year. In addition to the measures of proficiency in 5 school subjects (Physics, Chemistry, Mathematics, etc.) the specific tests used in the investigation were as follows: 4 performance tests (Passalong, Formboard, Kohs' Block Design and Cube Construction); a group test so constructed that some of its tests were supposed to measure the general factor (Classification Lines, Classification Figures, Figure and Completion, Letter Patterns and Number Puzzles), some the verbal factor (Completion, Analogies, Classification) and some a spatial factor (Rotation, Fitting Shapes, Form Relations and the Square Test), an individual reading test (from Burt's graded reading tests) and two individual sets of 5 problems each (modelled upon Burt's Reasoning

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[1] Shuttleworth's own interpretation of his two factors was—Practical Intelligence and a Mechanical-Spatial form of aptitude. In the opinion of the present writer this interpretation does not distinguish the two factors with sufficient clarity. See Shuttleworth's article entitled "Tests of technical aptitude," Occup. P., Vol. 16, 1942, p, 181.

[2] Price, E.J.J. "The nature of the practical factor (F)," B.J.P., Vol. 30, 1940, p. 349.

Test). Burt's summation method was used to obtain the general factor and the remaining bipolars; only two factors were found to be significant, one general and the other bipolar. The analysis revealed a bipolarity between the performance tests on the one hand and the scholastic subjects on the other; there appeared, however, to be no great differences in the factorial structue of the performance tests and the *k* tests. The average saturations of the 4 performance tests in the two factors were .48 and-.38, the corresponding saturations of the *k* tests being .41 and-.50.[1]

Drew's investigation which has been described elsewhere,[2] had a two-fold purpose, to determine the feasibility of measuring technical aptitude at the age of transfer when children are 11 years old, and to enquire into the relationship between F as measured by the tests in the Alexander Scale and *k* as measured by certain spatial tests. He studied 4 different groups of boys composed as follows:

Group	*Number*	*Mean Age*
A. Senior Elementary	181	11.9
B. Senior Elementary	172	12.11
C. Junior Technical	118	13 6
D. Junior Technical	88	15.8

The tests used in the study were: (1) General aptitude test. (2) Spearman's *gvk* test[3] (3) Alexander's Performance Scale—Passalong, Block Design and Cube Construction tests. For the first three groups, teachers' ratings on a seven-point scale of verbal and practical ability were also included and for group D the results of the Diploma Examination as a valid estimate of technical ability. Thurstone's method of factor-analysis was used throughout. Drew arrived at several conclusions[4] of great educational import, but his finding relevant to the present question may be phrased thus: F is measurable at 11 but *k* does not seem to emerge till about the age of 14. After 14 when both factors seem to be measurable the two factors are independent and not identical with each other. His interpretation of the two factors is that while F involves mental exercise of the concrete order, with manipulation and handling of material, shape and pattern being perceived and appreciated in the course of such operations, *k* seems "to be associated with spatial relations of an abstract order." In the opinion of the present writer this differentiation is not very clear. In addition to the apparently overlapping nature of the two factors as defined by Drew, there is also a serious methodological defect in the design of the whole experiment as conducted by him. In a research which was particularly designed to explore the existence and relationship of certain factors at different ages, he employed several groups of differing ages rather than study the same group at different ages. Drew himself was aware of the defect and wrote that "Ideally, the group for experiment should have remained the same with results obtained at 11, 12, 13 and 16." As matters stand, it is likely that error due to subjective interpretation necessary for the identification of the same factors in different age-groups has to an unknown extent vitiated the findings reported. To illustrate the point, one may legitimately ask, what is the guarantee that the F factor which Drew isolated in his performance tests with the 12 year old group is the same for which he found evidence in the performance tests with his 16 year old subjects and which in the latter group was further reported by him to be significantly related to success in the Junior Technical School Diploma Examination? Drew simply assumed that the two factors were the same, and in so doing begged the whole question.

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[1] Bradford, E.J.G. "Selection for technical education," B.J.E.P., Vol. 16, 1946, p. 27.

[2] See author's *Selection of children for Secondary Technical Education*, Studies in Education and Psychology, Publication Number 6, Central Institute of Education, Delhi, 1956, p. 4.

[3] This is the same specially constructed group test which was used by Bradford. See page 42.

[4] Drew, L.J. "An investigation into the measurement of technical ability," Occup.P., Vol. 21, 1947, pp. 34-48. Drew's findings, as stated elsewhere are not very reliable. His evidence regarding the independence of F and *k* as well as his other conclusions, therefore, cannot be regarded as very weighty.

Finally, Dempster reported an experiment in which 91 boys from a junior technical school were given a group of tests comprising verbal and spatial tests, a non-verbal test of intelligence and the tests of the Alexander Performance Scale. The data were factorised by the Centre of Gravity method and three factors extracted. "When these factors were rotated, two factors only emerged, one was very clearly verbal while with one exception... all the other tests, spatial and performance held closely together. This would appear to confirm Price's finding."[1]

The entire evidence bearing on the relationship between the three practical factors F, *m* and *k* may now be summarised. The investigations conducted by Koussy, Slater, Kerr and Shuttleworth employing inter alia *m* and *k* tests produced evidence suggesting that the functions concerned are identical. The researches carried out by Price, Bradford and Dempster employing

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[1] Dempster, J.J.B. "Symposium on the selection of pupils for different types of secondary schools, V, The Selector's point of view," B.J.E.P., Vol. 18, 1948, p. 125.

F and *k* tests suggested that the abilities concerned are identical. This finding was contradicted only by Drew whose own evidence, however, was far from satisfactory. The investigation reported by Alexander employing F and *m* tests failed to produce any definite evidence on the identity or otherwise of the two factors.

On the whole, therefore, we may be justified in drawing the inference that F, *m* and *k* broadly signify the same mental function whose essential activity may be described as thinking in terms of space-relations. This conclusion is further in harmony with the fact that in contemporary discussions on the nature of practical ability there is a strong tendency to represent the practical factor by the same letter—usually *k*—and interpret it in terms of the ability to think spatially.

The conclusion that seems to emerge from the foregoing review of researches on practical ability is that this ability as measured by performance tests or tests of mechanical ability or tests of space-perception seems to consist of two identifiable factors, namely, general intelligence and the ability to appreciate space relations. This does not mean that the score of a given child on a certain test of practical ability will be entirely dependent upon the two factors *g* and *k*; it is certain that in any particular test-performance, specific factors will also come into the picture. All that is meant is that the two factors that appear to be more constantly present than others in tests of practical ability are *g* and *k*.

BIBLIOGRAPHY

Alexander, W.P.	"A New Performance Test of Intelligence". The British Journal of Psychology, vol. 23, 1932, 52-63.
-do-	*Instruction Book, A Performance Scale for the Measurement of Practical Ability.* Thomas Nelson & Sons Ltd., Edinburgh. 1946.
-do-	"Intelligence, Concrete and Abstract". The British Journal of Psychology, Mon. Supplement 19, 1935.
Allen, E.P.	"The Selection of Engineering Apprentices", The Journal of National Institute of Industrial Psychology, vol. 5, 1931, pp 379-384.
-do-	"Vocational Guidance: The Birmingham Experiment". The Human Factor, vol. 6, 1932, pp. 170-173.
Allen, E.P. and Smith, P.	*Selection of Apprentices for the Engineering Trades.* City of Birmingham Education Committee. Three Reports, 1931, 1934 and 1939.
-do-	"The Selection of Engineering Apprentices II". The Human Factor, vol. 9, 1935, pp. 63-67.
-do-	*The Value of Vocational Tests as Aids to Choice of Employment.* City of Birmingham Education Committee, Report 1932.
Attenborough, J. and Farber, M.	"The Relation between Intelligence, Mechanical Ability and Manual Dexterity in special School Children", The British Journal of Educational Psychology, vol. 4, 1934, pp. 140-161.
Bebcock, H.	"The Short Army Performance Scale in Clinical Practice", The Journal of Applied Psychology, vol. 16, 1932, pp. 532-548.
Baldwin, E.F. and Smith, L.F.	"The Performance of Adult Female Applicants for Factory Work on the Likert-Cuasha Revision of the Minnesota Paper Form Board Test", The Journal of Applied Psychology, vol. 28, 1944, pp. 468-470.

Bennett, G.K. and Cruikshank, R.M. “Sex Differences in the Understanding of Mechanical Problems”, The Journal of Applied Psychology, vol. 26, 1942, pp. 121-127.

-do- *A Summary of Manual and Mechanical Ability Tests*, The Psychological Corporation, New Yark, 1942.

Benton, A.L. “A Study of the Performances of Young Adults on the Kohs Block Design Test”, The Journal of Applied Psychology, vol. 25, 1941, pp. 420-427.

Blakey R. I. “A Factor Analysis of a Non-Verbal Reasoning Test,” Educational and Psychological Measurement, Vol. 1, 1941, pp. 187-198.

Board of Education. *Secondary Educatian with Special Reference to Grammar Schools and Technical High Schools.* (Spens Report) His Majesty’s Stationery Office, London, 1938.

-do- *The Education of the Adolescent.* (Hadow Report) His Majesty’s Stationery Office, London, 1927.

Bousfield, W.A. “A Study of Motor Skill in the Free Hand Duplication of Geometrical Figures”. The Journal of Applied Psychology, vol. 14, 1930, pp. 478-485.

Brush, E.N. “Mechanical Ability as a Factor in Engineering Aptitude”, The Journal of Applied Psychology, vol. 25, 1941, pp. 300-312.

Burr, E.T. and Metcalfe, Z. “I.E.R. Girls’ Assembly Test Revised Norms Based on Short Form”, The Journal of Applied Psychology, vol. 21, 1937, pp. 372-378.

Burt, C. Review of “An Analysis of Performance Test Scores of a Representative Group of Scottish Children”, The British Journal of Educational Psychology, vol. 10, 1940, pp. 238-244.

-do- “Mental Abilities and Mental Factors”, The British Journal of Educational Psychology, vol. 14, 1944, pp. 85-94.

-do- *Mental and Scholastic Tests*, Staples Press Ltd., London, 1947 (ed).

Burt, C.	*The Distribution and Relations of Educational Ability*, P. S. King & Son Ltd., London, 1917.
-do-	*The Factors of the Mind*, University of London Press, Ltd., London, 1940.
Buxton, C.	"The Application of Multiple Factorial Methods to the Study of Motor Ability", Psychometrika, vol. 3, 1938, pp. 85-93.
Campbell, M.	"The Cognitive Aspects of Motor Performances and Their Bearing on General Motor Ability", Journal of Experimental Psychology vol. 19, 1936, pp. 323-333.
-do-	"An Experimental Evaluation of the Significance of Three Factors Involved in Motor Performances for General Motor Ability", Journal of Experimental Psychology, vol. 19, 1936, pp. 612-620.
Clarke, G.	"The Range and Nature of the Factors in Perceptual Tests", 1937, Ph.D. Thesis in the University of London Library.
Cockett, R.	"The Nature of Performance Tests : An Experimental Study", The British Journal of Psychology, vol. 38, 1947, pp. 29-38.
Cooper, C.L.	"Mechanical Aptitude and School Achievement of Negro Boys", The Journal of Applied Psychology, vol. 20, 1936, pp. 751-760.
Cox, J.W.	*Manual Skill, Its Organization and Development*, Cambridge at the University Press, 1934.
-do-	*Mechanical Aptitude*, Methuen & Co., Ltd., London, 1928.
Crockett, A.C.	"A Measure of Manual Ability", The Journal of Applied Psychology, vol. 14, 1930, pp. 414-426.
Dearborn, W.F., Shaw, E.A. and Lincoln, E.A.	"A Series of Formboard and Performance Tests of Intelligence", Harvard Monographs in Education, 4, 1923.
Dodd, S. C.	*International Group Mental Tests*, Princeton, 1926, pp. 101.
Drever, J. and Collins, M.	*Performance Tests of Intelligence*, Oliver and Boyd, Edinburgh, 1944 (ed).

Drew, L. J. “An Investigation into the Measurement of Technical Ability”, Occupational Psychology, Vol 21, 1947, pp. 34-48.

Eells, W.C. “Mechanical, Physical and Musical Ability of the Native Races of Alaska”, The Journal of Applied Psychology, vol. 17, 1933, pp. 493-506.

Farmer, E. “A Group Factor in Sensory-Motor Tests”, The British Journal of of Psychology, vol. 17, 1927, pp. 327-334.

Fortes, M. “A New Application of the Theory of Noegenesis to the Problem of Mental Testing”, 1930, Ph.D. Thesis in the London University Library.

Frandsen, A.N. “Mechanical Ability of Morons”, The Journal of Applied Psychology, vol. 19, 1935, pp. 371-378.

Gaw, F. “A Study of Performance Tests”, The British Journal of Psychology, vol. 15, 1925, pp. 374-392.

-do- “The Use of Performance Tests and Mechanical Tests in Vocational Guidance”, The Journal of the National Institute of Industrial Psychology, vol. 1. 1923, pp. 333-337.

Goodman, C H. “The MacQuarrie Test for Mechanical Ability”, The Journal of Applied Psychology, vol. 31, 1947, pp. 150-154.

Granit, A.R. “A Study on the Perception of Form”, The British Journal of Psychology, vol. 12, 1921, pp. 223-247.

Griffitts, C.H. “A Study of Some ‘Motor-Ability’ Tests”, The Journal of Applied Psychology, vol. 15, 1931, pp. 109-125.

Guilford J.P. and Guilford, R.B. “A Prognostic Test for Students in Design”, The Journal of Applied Psychology, vol. 15, 1931, pp. 335-345.

Hanmen, B. “The Performance of Adult Males on the Minnesota Paper Form Board Test and the O'Rourke Mechanical Aptitude Test”, The Journal of Applied Psychology, vol. 26, 1942, pp. 809-811.

Harding, D.W.	"Prognostic Tests for Students of Architecture", Occupational Psychology, vol. 17, 1943, pp. 126-138,
Harrell, W.	"A Factor Analysis of Mechanical Ability Tests", Psychometrika, vol. 5, 1940, pp. 17-33.
Harvey, O.L.	"Mechanical 'Aptitude' or Mechanical 'Ability'? A Study in Method", The Journal of Educational Psychology, vol. 22, 1931, pp, 517-522.
Heston, J.C.	"A Factor Analysis of some Clinical Performance Tests", The Journal of Applied Psychology, vol. 27, 1943, pp. 135-149.
Hiskey, M.S.	"A New Performance Test For Young Deaf Children", Educational and Psychological Measurement, vol. 1, 1941, pp. 217-232.
Holliday, F.	"A Survey of an Investigation into the Selection of Apprentices for the Engineering Industry", Occupational Psychology, vol. 16, 1942, pp. 1-19.
-do-	"The Relation Between Psychological Test Scores And Subsequent Proficiency of Apprentices in the Engineering Industry", Occupational Psychology, vol. 17, 1943, pp.168-185.
Hunt, E.P. and Smith, P.	*Scientific Vocational Guidance and Its Value to the Choice of Employment Work of a Local Education Authority*. City of Birmingham Education Committee Report, 1944.
-do-	"Vocational Guidance Research: Ten Years' Work by the Birmingham Education Committee", Occupational Psychology, vol. 12, 1938, pp. 302-307.
Hutt, M.L.	"The Kohs Block-Design Test. A Revision for Clinical Practice", The Journal of Applied Psychology, vol. 16, 1932, pp. 298-307.
Industrial Fatigue Research Board	Report, 33 (*A Study in Vocational Guidance* by F. Gaw, L. Ramsey, M. Smith and W. Spielman), 1926.
-do-	Report 53. (*The use of Performance Tests of Intelligence in Vocational Guidance* by F. M. Earle, M. Milner, etc.) 1929.

Jennings, J.R. and Stott, M.B.	"A Fourth Follow-up of Vacationally Advised Cases (1930-1)". The Human Factor, vol. 10, 1936, pp. 165-174.
Karpeles, L.M.	"A Further Investigation of the Porteus Maze Test as a Discriminative Measure in Delinquency". The Journal of Applied Psychology, vol 16, 1932, pp. 427-437.
Kelley, T.L.	"A Constructive Ability Test" The Journal of Educational Psychology, vol. 7, 1916, pp. 1-16.
Koran, S.W.	"Performance testiug in Public Personne Selection, Part I", Educational and Ptychological Measurement, vol. 1, 1941, pp. 233-252.
-do-	"Performance Testing in Public Personnel Selection, Part II", Educational and Psychological Measurement, vol. 1, 1941, pp. 365-386.
Koussy, A.A.H. El.	"An Investigation into the Factors in Tests Involving the Visual Perception of Space", The British Journal of Psychology, Mon. Supp. 20, 1935.
Line, W.	"The Growth of Visual Perception in Children", The British Journal of Psychology, Mon. Supp. 15, 1931.
MacMeeken, A.M.	*The Intelligence of a Representative Gronp of Scottish Children*, Universisy of London, Press Ltd., London, 1939.
Macrae, A.	"A Borstal Experiment in Vocational Guidance: A Critical Notice", The Human Factor, vol. 11, 1937, pp. 187-189.
-do-	A Third Follow-up of Vocationally Advised Cases (1029)", The Human Factor, vol. 7 1933, pp. 41-50.
-do-	*Talents and Temperaments*, Nisbet & Co., Ltd., London, 1932.
Maier, N.R.F.	*Psychology in Industry*, George G. Harrap & Co., Ltd., London, 1947.
McCloy, C.H.	"The Measurement of Speed in Motor Performance", Psychometrika, vol. 5, 1940, pp. 173-182.

McFarlene, M. "A Study of Practical Ability", The British Journal of Psychology, Mon. Supp. 8 1925.

Metcalfe, Z and Burr, E.T. "A Practical Form of the Girls, Mechanical Assembly Test", The Journal of Applied Psychology, vol. 20, 1936, pp. 672-679.

Murdoch, K. "A Study of the Comparative Value of Nine Performance Tests", The Journal of Applied Psychology, vol. 9, 1925, pp. 364-366.

Muscio, B. "Motor Capacity with Special Reference to Vocational Guidance", The British Journal of Psychology, vol. 13, 1922, pp. 157-184.

Myers, C.S. "Recent Evidence of the Value of Vocational Guidance", The Human Factor, vol. 6, 1932, pp 438-450.

Newell, C.D. "The Uses of the Form Board in the Mental Measurement of Children", Psychological Bulletin, vol. 28, 1931, pp. 309-318.

Nissen, H.W., Macnover, S. & Kinder, E F. "A Study of Performance Tests Given to a Group of Native African Negro Children", The British Journal of Psychology, vol. 25, 1935, pp. 308-355.

Oakley, C.A. "A First Survey of Psychological testing in Secondary and Other Schools—1", The Human Factor, vol. 9, 1935, pp. 138-146.

Page, M.L. "The Mechanical Ability of Sub-normal Boys", The Journal of Applied Psychology, vol. 17, 1933, pp. 164-181.

Paterson, D.G. et al. *Minnesota Mechanical Ability Tests*, The University of Minnesota Press, Minneapolis, 1930.

Peel, E.A. "Symposium on Selection of Pupils for Different Types of Secondary Schools, VI—Evidence of a Practical Factor at the Age of Eleven", The British Journal of Educational Psychology, vol. 19, 1949, pp. 1-15.

Phillip, B.R. "The Relationship Between Speed and Accuracy in a Motor Task", Journal of Experimental Psychology, vol. 19, 1936, pp.24-50.

Pintner, R. "A Non-Language Group Intelligence Test", The Journal of Applied Psychology, vol. 3, 1919, pp. 199-214.

Pintner, R. & Paterson, D.G.	*A scale of Performance Tests*, D. Appleton & Co., New York, 1923.
Portenier, L.G.	"Mechanical Aptitudes of University Women", The Journal of Applied Psychology, vol. 29, 1945, pp. 477-482.
Porteus, S.D.	*The Psychology of a Primitive People*, Edward Arnold & Co., London, 1931.
Rao, K.G.R.	"Comparative Value of Certain Verbal and Non-Verbal (Primarily Perceptual) Tests and Their Relation to Tests of Mechanical Ability", 1933 Ph.D. Thesis in the London University Library.
Rodger, A.	"A Borstal Experiment in Vocational Guidance" The British Journal of Educational Psychology, vol. 3, 1933, pp. 127-141.
-do-	"The Use of Tests in Vocational Guidance", Occupational Psychology, vol. 13, 1939, pp. 200-210.
-do-	"Vocational Guidance: A Review of Some Doubts", Occupational Psychology, vol. 12, 1938, pp. 187-195.
Rusmore, E.J.T.	"Comparison of an 'Industrial' Problem Solving Task and an Assembly Task", The Journal of Applied Psychology, vol. 28, 1944, pp. 129-131.
Shuttleworth, C.W.	"Tests of Technical Aptitude", Occupational Psychology, vol. 16, 1942, pp. 175-182.
-do-	"Tests of Mechanical Aptitude", 1942, M.A. Thesis in the University of London Library.
Simpson, R.M.	"The Mechanical Aptitudes of 312 Prisoners", The Journal of Applied Psychology, vol. 16, 1932, pp. 485-496.
Slater, P.	"Some Group Tests of Spatial Judgment or Practical Ability", Occupational Psychology, vol 14, 1940, pp. 40-55.
Smith, I.M.	"Measuring Spatial Ability in School Pupils", Occupational Psychology, vol. 22, 1948, pp. 150-159.
Spearman, C.	"General Ability, Its Existence and Nature", The British Journal of Psychology, vol. 5, 1912, pp. 51-84.

Spearman, C. *The Abilities of Man*, Macmillan & Co. Ltd., London, 1927.

Stalnaker, J.M. "Results from Factor Analysis, with Special Reference to 'Primary Mental Abilities", Journal of Educational Research, vol. 33, 1940, pp. 698-704.

Stenquist, J. L. *Measurement of Mechanical Ability*, Teachers College, Columbia University, New York, 1923.

-do- "The Case for the Low I. Q.", Journal of Educational Research, Vol. 4, 1921, pp. 241-254.

Tagg, M. "The Selection of Engineering Apprentices,"The Journal of the National Institute of Industrial Psychology, vol. 2, 1924, pp. 129-133.

-do- "The 'Make-Up' of the Engineering Worker," The Journal of the National Institute of Industrial Psychology, Vol. 1, 1923, pp. 313-324.

The National Institute of Industrial Psychology. "A Follow-Up of Vocationally Advised Cases", The Human Factor, vol. 11, 1937, pp. 16-26.

-do- "A first Follow-Up of Scottish Vocationally Advised Cases", The Human Factor, vol. 11, 1937, pp. 27-31.

-do- Report 3. (*Tests of Mechanical Ability* by F. M. Earle, A. Macrae and other members of the Institute's staff), 1929.

-do- Report 4. (*The Measurement of Manual Dexterities*, by F.M. Earle, assisted by F. Gaw and other members of the Institute's staff), 1930.

-do- Report 6. (*A Vocational Guidance Research in Fife* by F.M. Earle and J. Kilgour), 1935.

Thompson, C. E. "Motor and Mechanical Abilities in Professional Schools", The Journal of Applied Psychology, Vol. 26, 1942, pp. 24-37.

Thomson, G.H. *An Analysis of Performance Test Scores of a Representative Group of Scottish Children*, University of London Press, Ltd. London, 1940.

Thomson, G.H.	"The Speed Factor in Performance Tests", The British Journal of Psychology, vol. 32, 1941, pp. 131-135.
Thorndike, E.L.	"A Standardised Group Examination of Intelligence Independent of Language", The Journal of Applied Psychology, vol. 3, 1919, pp. 13-32.
Thurstone, L. L.	*Primary Mental Abilities*, The University of Chicago Press 1938.
-do-	"The Factorial Isolation of Primary Abilities", Psychometrika, Vol. 1, 1936, pp. 175-182.
-do-	"The Perceptual Factor", Psychometrika, Vol. 3, 1938, pp. 1-17.
Tuckman, J.	"A Comparison of Norms for the Minnesota Rate of Manipulation Test", The Journal of Applied Psychology, vol. 28, 1944, pp. 121-128.
Vernon, P.E.	"Psychological Tests in the Royal Navy, Army and A.T.S.", Occupational Psychology, vol. 21, 1947, pp. 53-74.
-do-	"Research in Personnel Selection in the Royal Navy and the British Army", The American Psychologist, vol. 2, 1947, pp. 35-51.
Wallin, W.	*Abnormal and Clinical Psychology*, George G. Harrap & Company Ltd., London, 1927.
Williams, H.S.	"Some Aspects of the Measurement and Maturation of Mechanical Aptitude in Boys Aged Twelve to Fourteen", 1948, Ph.D. Thesis in the London University Library.
Yoakum, C.S., & Yerkes, R.M.	*Mental Tests in the American Army*, Sidgwick & Jackson, London, 1920.